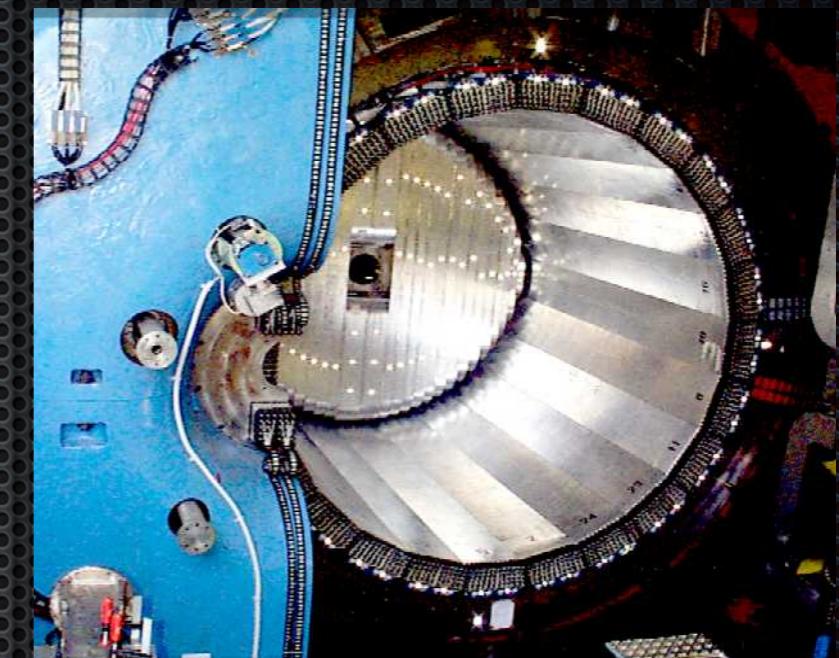
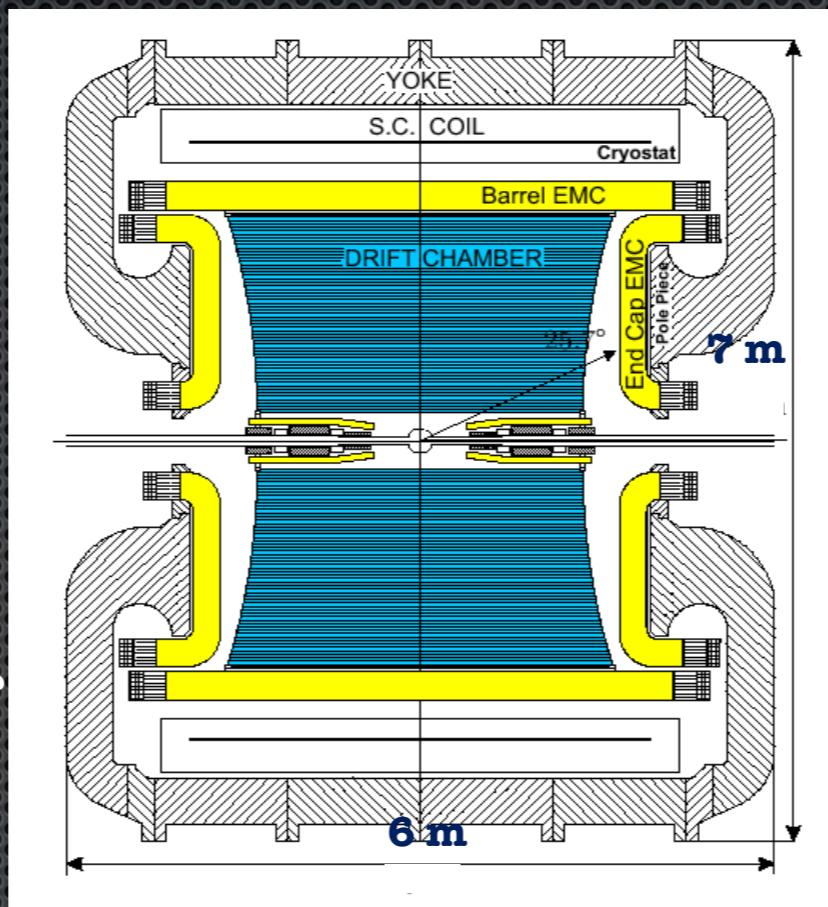


Status of the KLOE-2 Inner Tracker

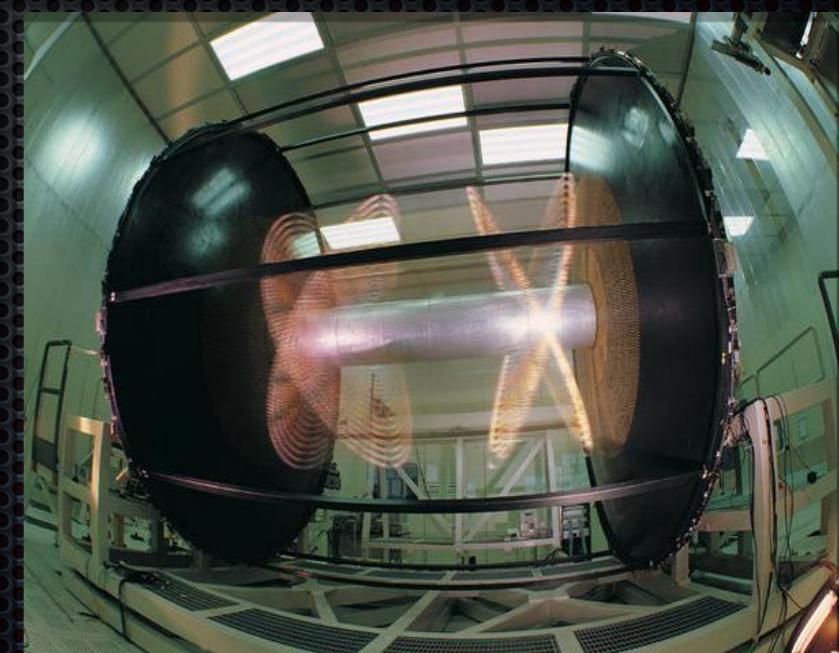
E. De Lucia
LNF- INFN
for the KLOE-2 Collaboration

KLOE-2 at DAFNE

- ◎ Calorimeter System
 - ⊕ EMC - Lead / Scintillating Fibers w PMT



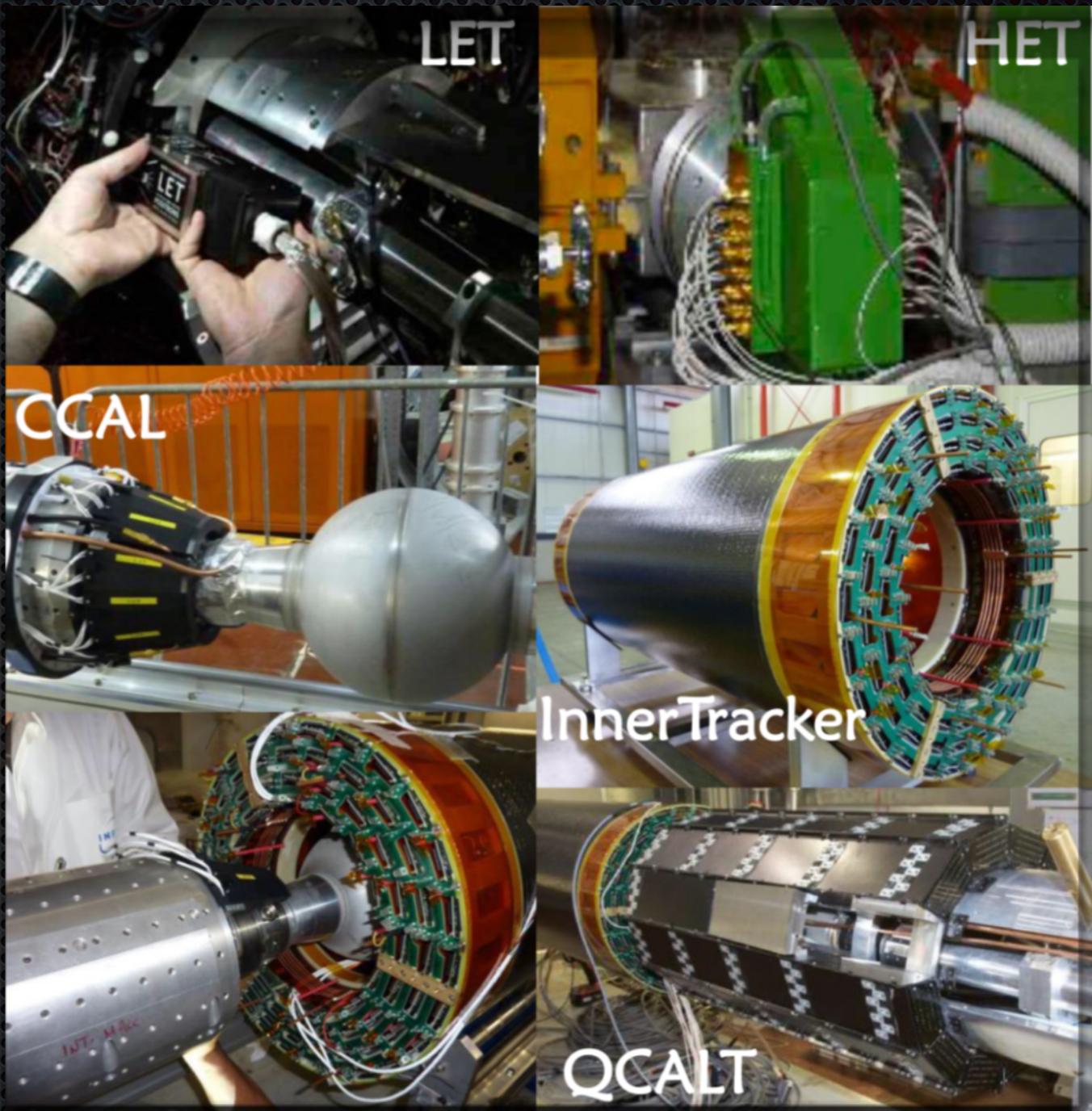
- ◎ Tracking System
 - ⊕ DC - He-Iso 90-10
3.7m x 4m Drift Chamber



- ◎ Superconductive Magnet
 - ⊕ 0.52 T solenoidal field
- ◎ DAFNE φ -factory
 - ⊕ $e^+ e^-$ at 1020 MeV

KLOE-2 at DAFNE

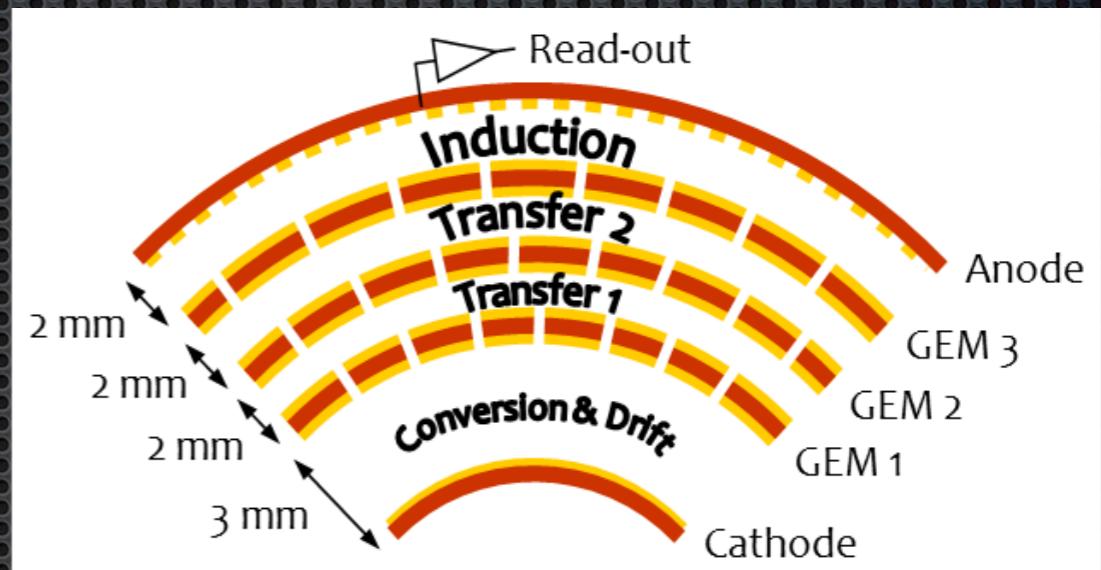
- ◎ Calorimeter System
 - ⊕ EMC - Lead / Scintillating Fibers w PMT Barrel and Endcaps
 - ⊕ LET / LYSO+SiPMs
 - ⊕ HET / Scint+PMTs
 - ⊕ QCAL - Tungsten / Scintillating Tiles w SiPM Quadrupole Instrumentation
 - ⊕ CCAL - LYSO Crystal w SiPM - Low-beta
- ◎ Tracking System
 - ⊕ DC - He-Iso 90-10 3.7m x 4m Drift Chamber
 - ⊕ Inner Tracker - 4 Cylindrical GEM detectors
- ◎ Superconductive Magnet
 - ⊕ 0.52 T solenoidal field
- ◎ DAFNE ϕ -factory
 - ⊕ $e^+ e^-$ at 1020 MeV



- ◎ Physics program [EPJC 68 (2010)]
 - ⊕ K_S , η , η_S rare decays
 - ⊕ Quantum Interferometry
 - ⊕ Dark photon search

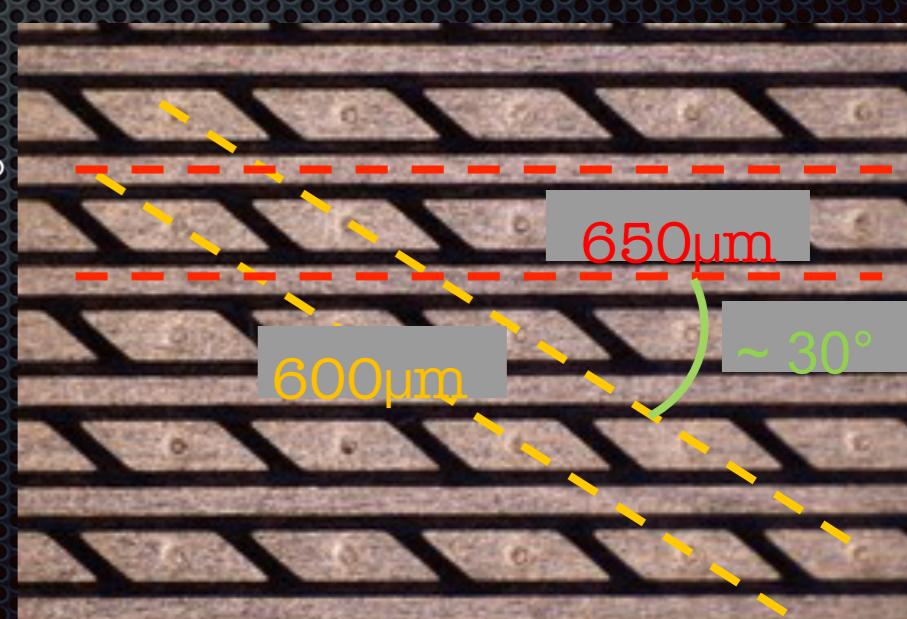
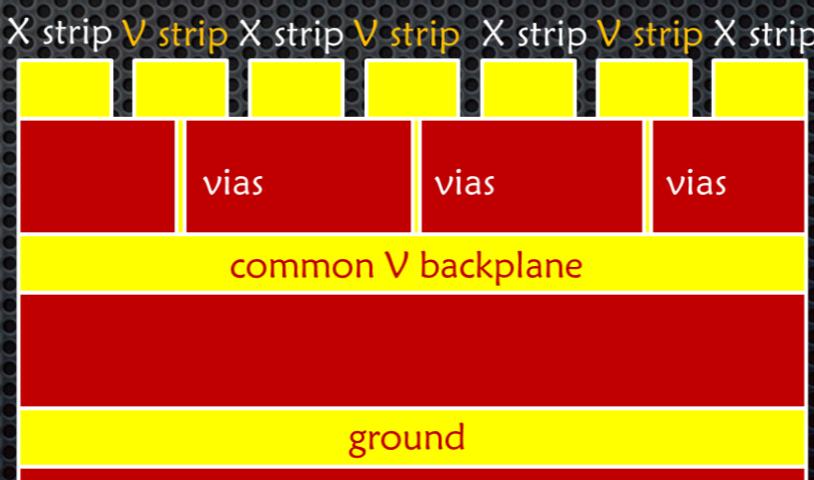
KLOE-2 CGEM Inner Tracker

- ◎ First batch ever of GEM foils produced with a **single-mask etching** technique developed by CERN-TE-MPE-EM and RD51 to produce large area foils
- ◎ 70 cm active length
- ◎ 650 μm XV pitch strip readout
- ◎ 25k chans GASTONE FEE [NIM A 732 (2013)]
- ◎ 1600 HV channels
- ◎ FEE DAQ system [JINST 08 T04004 (2013)]
- ◎ 3/2/2/2 mm triple-GEM layout
- ◎ Ar/Iso:90/10 gas mixture
- ◎ 12000 gas gain
- ◎ 2% X_0 material budget



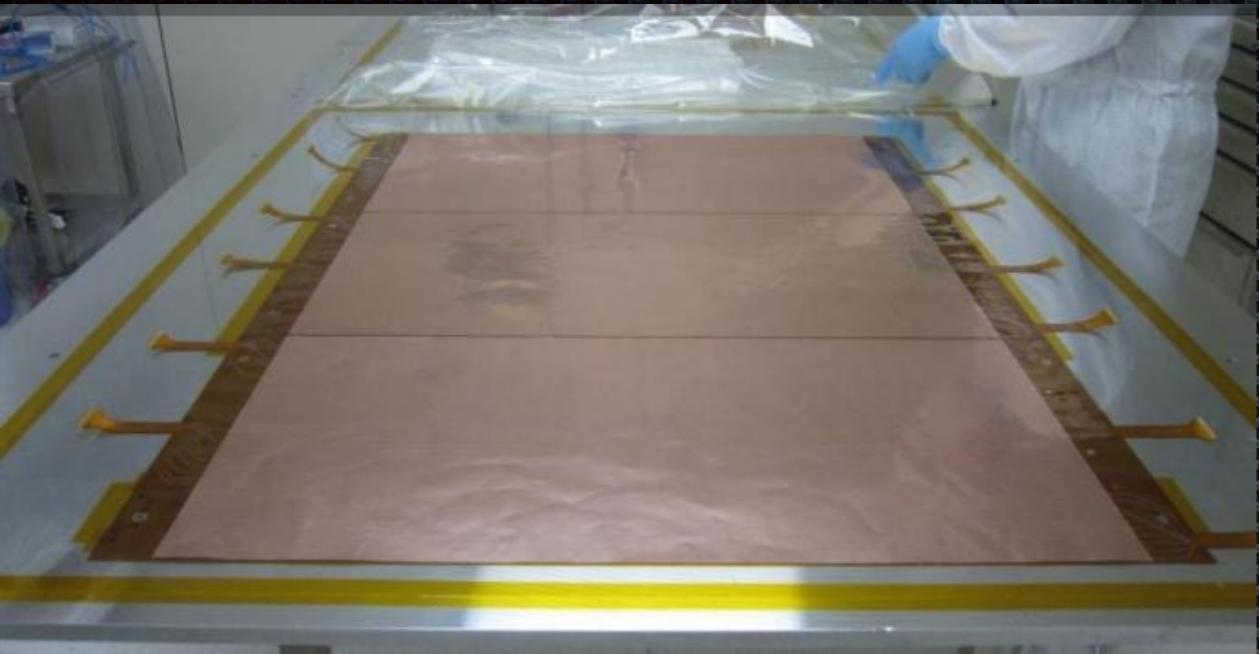
Kapton/copper multilayer flexible circuit built at CERN TE-MPE-EM (Tot thickness 300 μm)

- ◎ X-view: longitudinal strips
- ◎ V-view: connection of pads through conductive vias and a common backplane

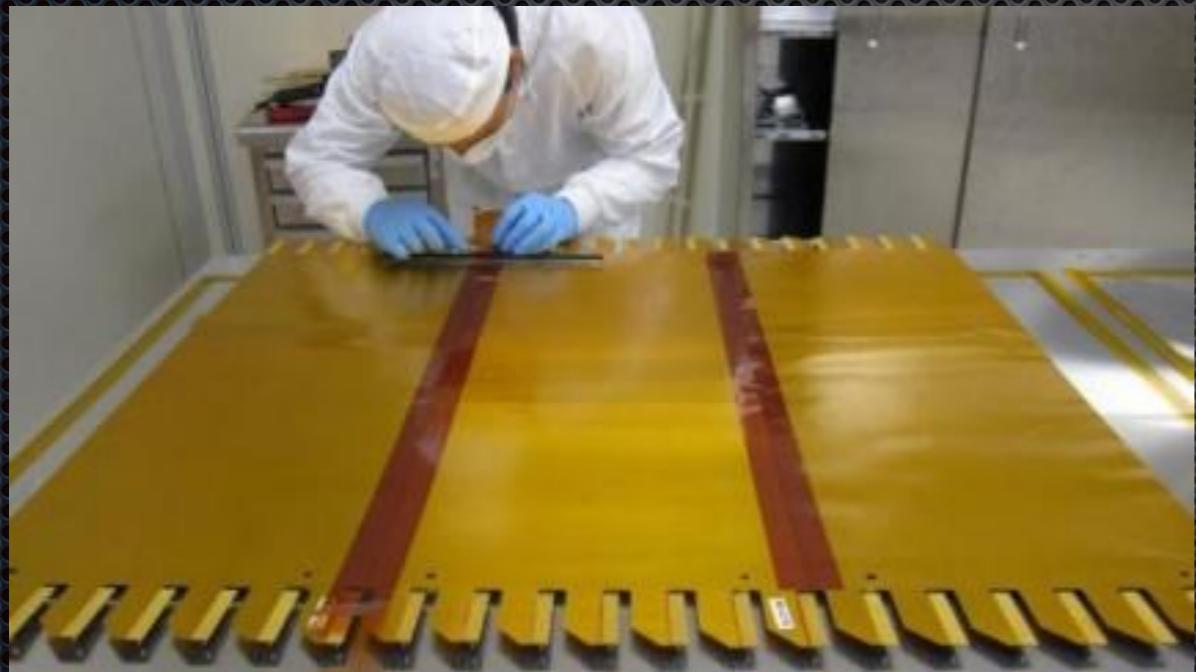


Cylindrical GEM detector construction

- ◎ Novel technique developed at LNF



- ◎ 3 GEM foils spliced together with 3 mm overlap



3 anode readout foils spliced w/o overlap:
6 cm kapton strips glued head-to-head joints

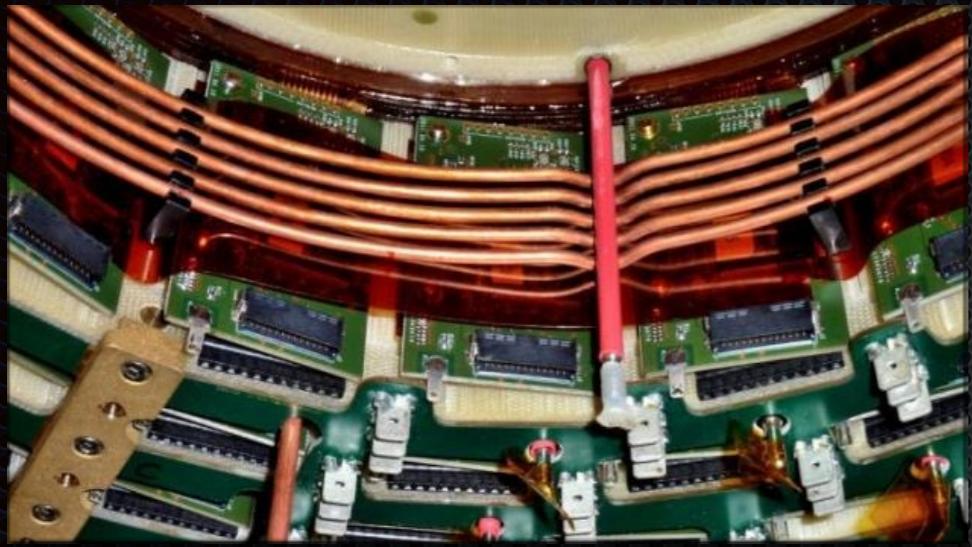


- ◎ GEM rolled on a cylindrical mold



- ◎ The GEM mold is fixed at the bottom of the insertion machine.
Readout plane is fixed at the top.
Electrodes are axially aligned with a precision of 0.1mm/1.5m

Cooling and Temperature control



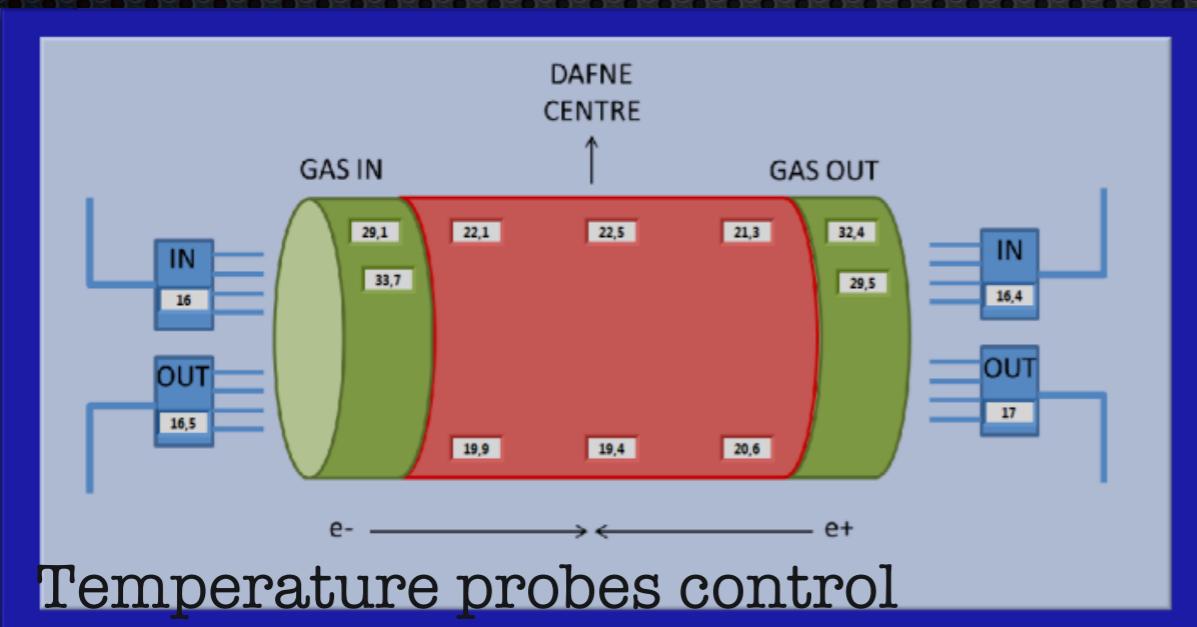
- IT Cables per side:
 - 90 readout cables
 - 69 HV cables
 - 36 gas tubes
 - 8 cooling tubes
 - 6 temp. probes

Heat sources

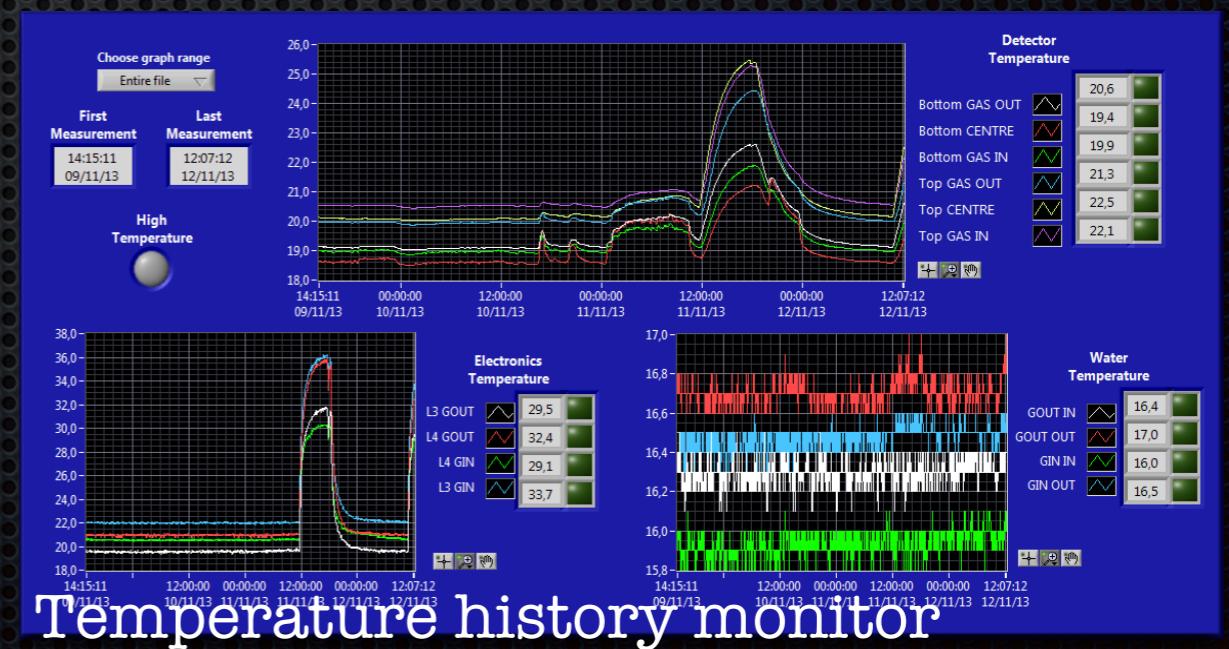
- Beam-pipe (luminosity dependent)
- FEE: 180 chips = 100W per side

Two dedicated cooling systems

- Air blowing between BP and IT
- Water radiators on FEE



Temperature probes control



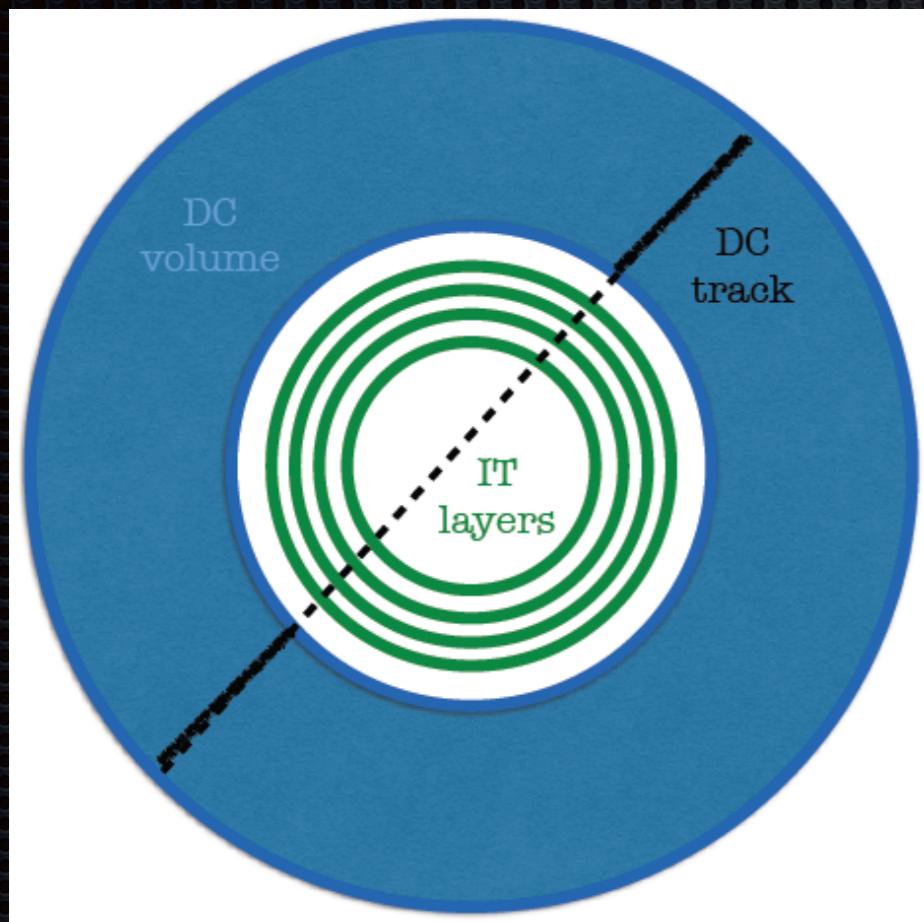
Inner Tracker working point

First CGEM detector used in high-energy physics experiment

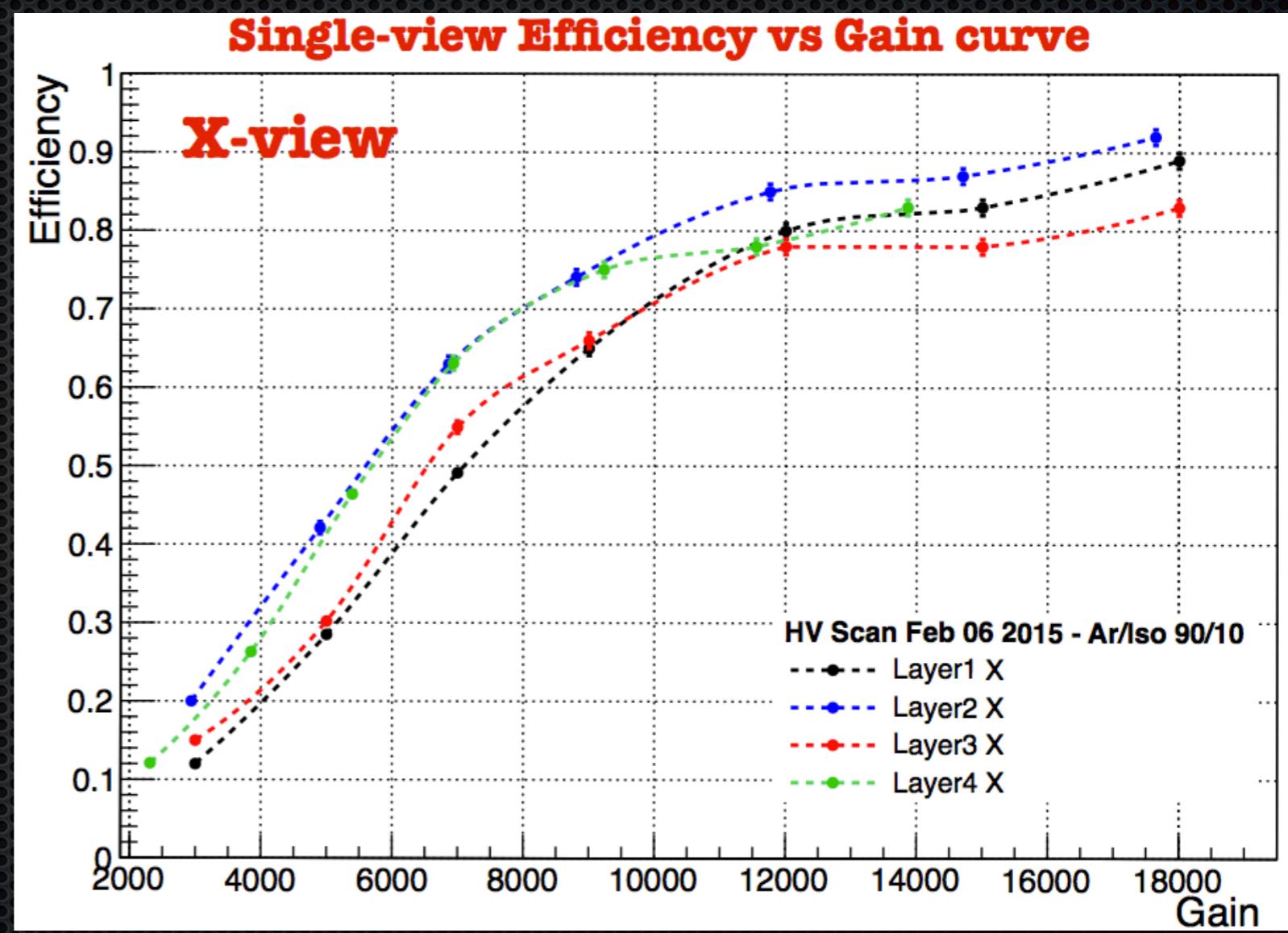
Operation point optimization (I)

Cosmic-ray muon data:

- ◎ Monitor detector noisy/dead channels situation and mask them in DAQ
- ◎ Extrapolate DC tracks to IT with straight-line approximation
- ◎ Look for reconstructed IT clusters close to expected positions from DC track



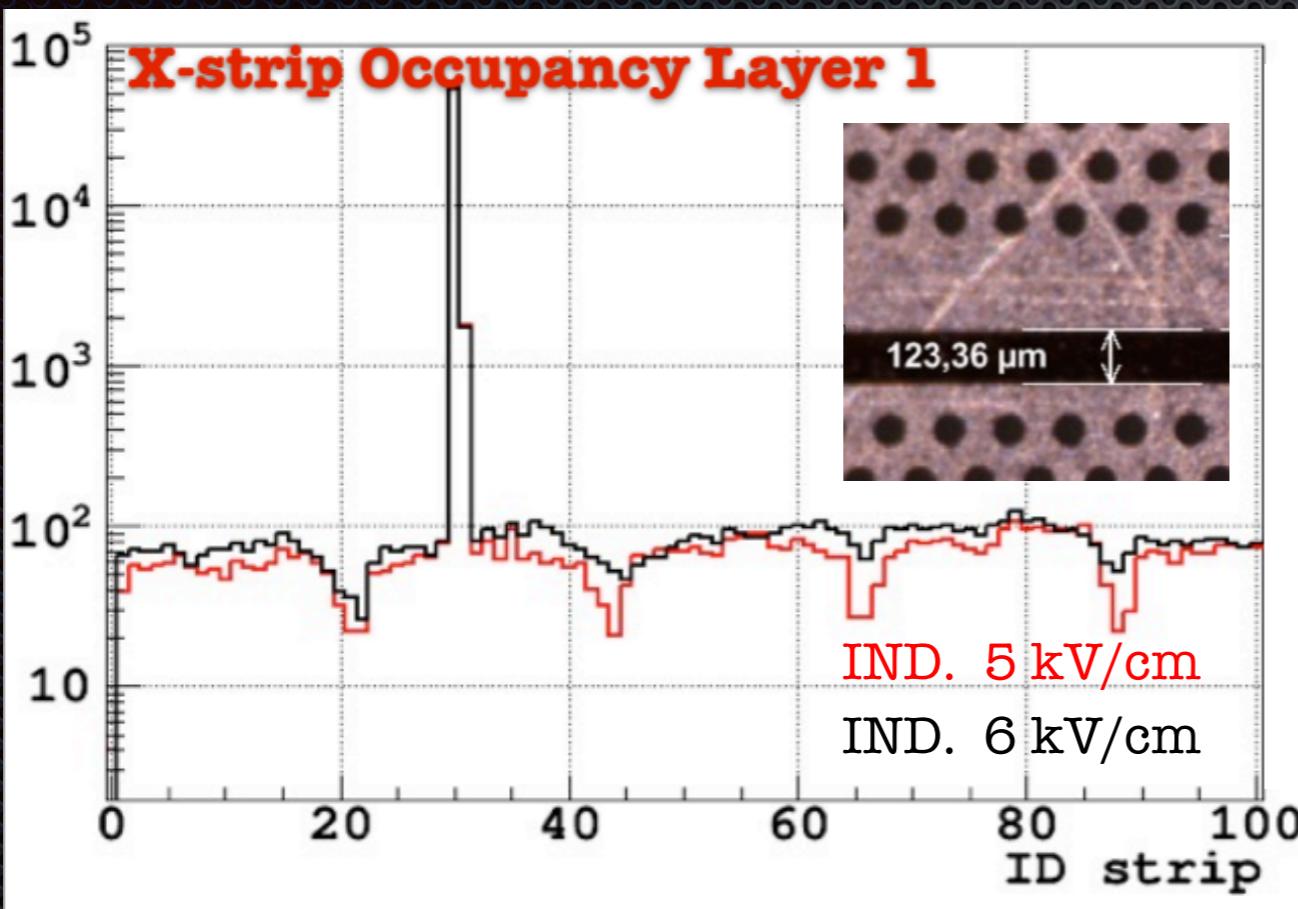
	(kV/cm)			(V)		
Drift	T1	T2	IND.	G1	G2	G3
1,5	3	3	5	285	280	265



- ◎ Compromise between good efficiency and stable detector operation with beams

Operation point optimization (II)

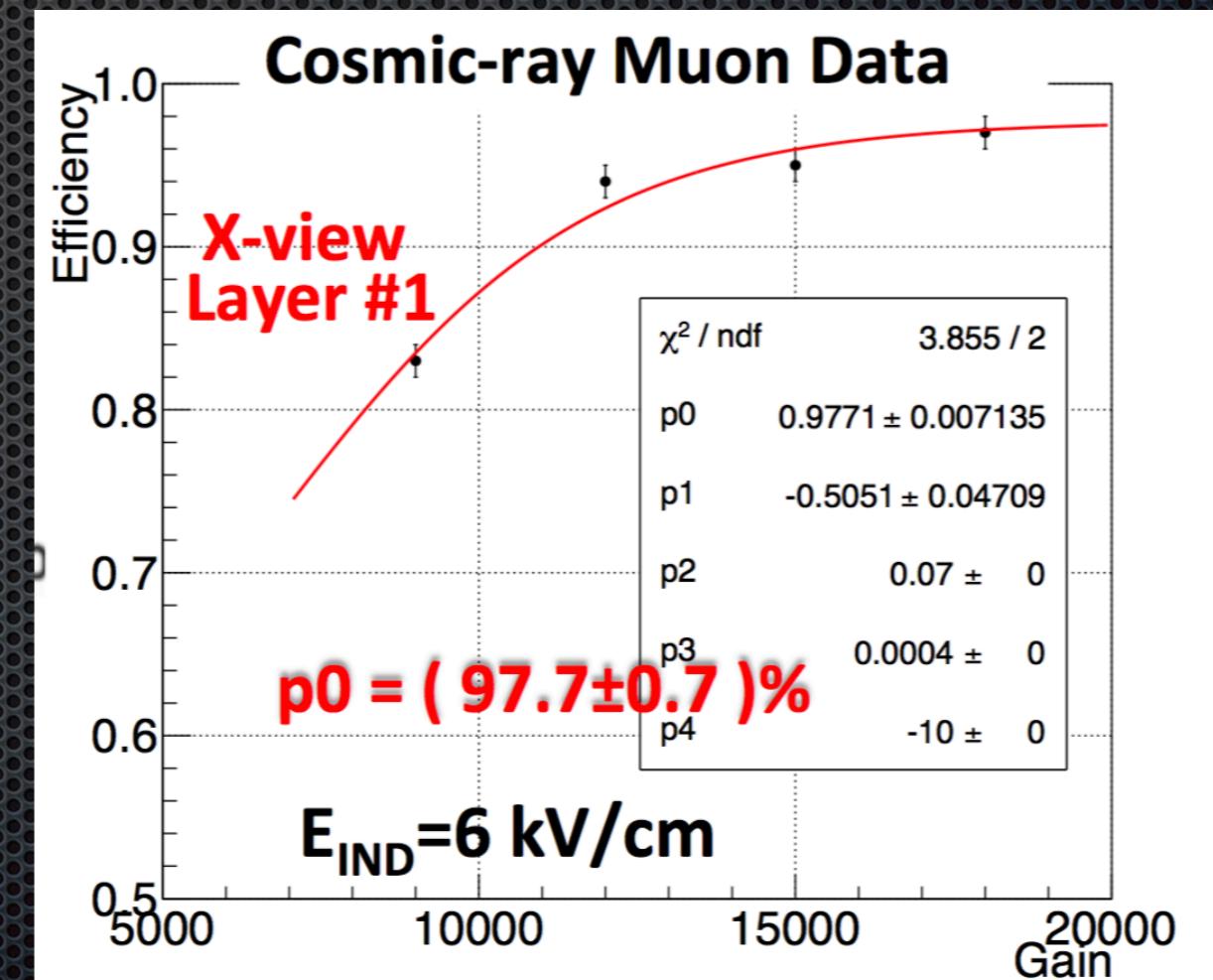
- ◎ Dips in the occupancy distribution show the micro-sector structure of GEM foils



	(kV/cm)		(V)	
Drift	T1	T2	IND.	G1
1,5	3	3	5	285
			G2	280
			G3	265

- ◎ Induction field increased from **5 kV/cm** to **6 kV/cm**

$$\varepsilon_{(5 \text{ kV/cm})} = 86 \% \rightarrow \varepsilon_{(6 \text{ kV/cm})} = 94 \%$$



- ◎ Compromise between good efficiency and stable detector operation with beams

Align & Calibrate CGEM detector

Challenging. Never done before.

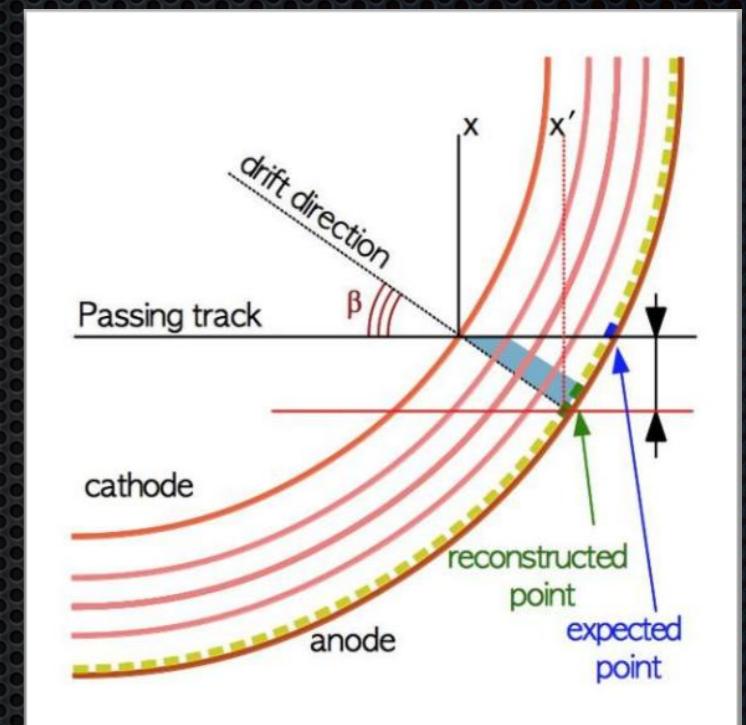
Detector Calibration strategy

1. NON-RADIAL TRACKS

The angle formed by a track and the radial E-field direction introduces: **shift & spread** of the e- cloud

2. MAGNETIC FIELD

0.52 T B-field orthogonal to Triple-GEMs E-fields: **shift** $\Delta x(a_L)$ and **larger spread of the electron cloud**



Detector Calibration strategy

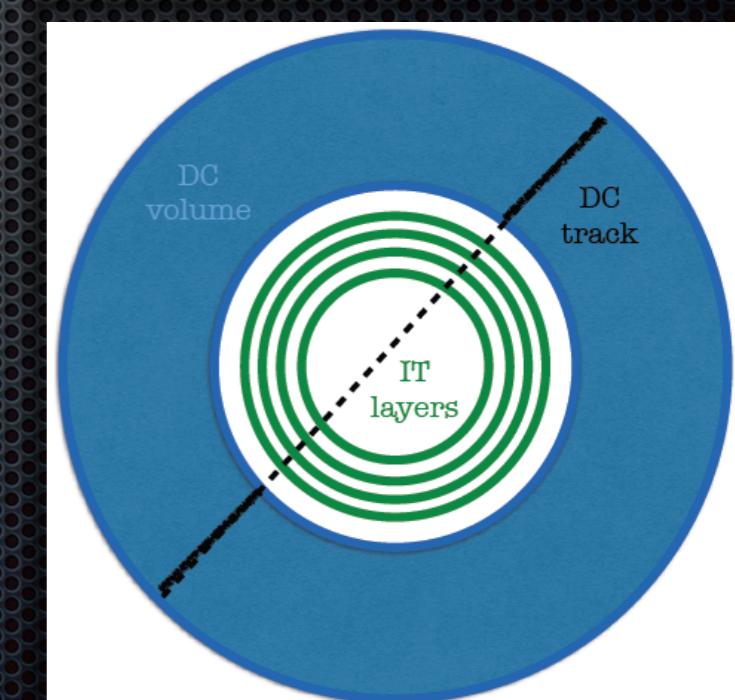
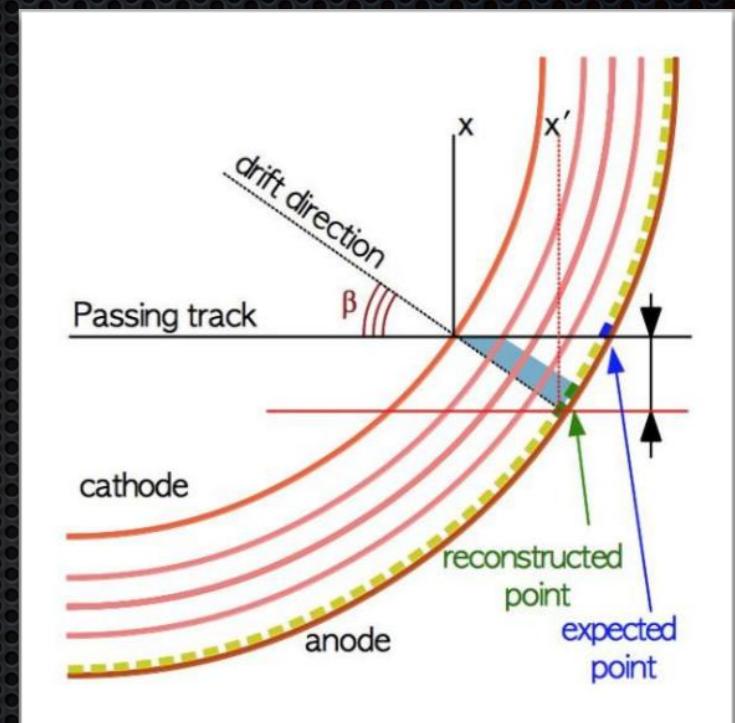
1. NON-RADIAL TRACKS

The angle formed by a track and the radial E-field direction introduces: **shift & spread** of the e- cloud

- ◎ Cosmic-ray muon data acquired with B-field OFF
 - + Calibration of Non-radial track effect
 - + Select DC tracks crossing IT at 2 points
 - + Corrections as a function of track parameters
 - + Shifts and rotations to align the IT

2. MAGNETIC FIELD

0.52 T B-field orthogonal to Triple-GEMs E-fields: **shift** $\Delta x(a_L)$ and **larger spread of the electron cloud**



Detector Calibration strategy

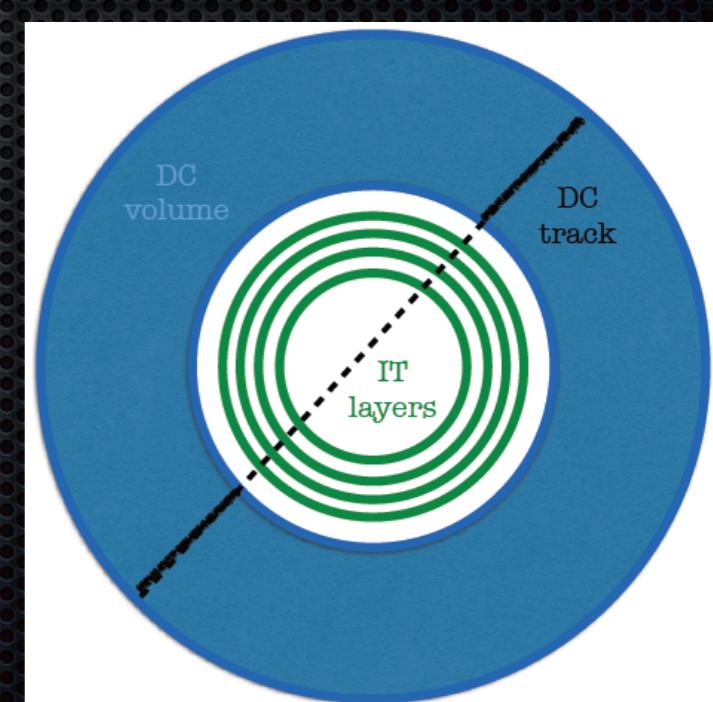
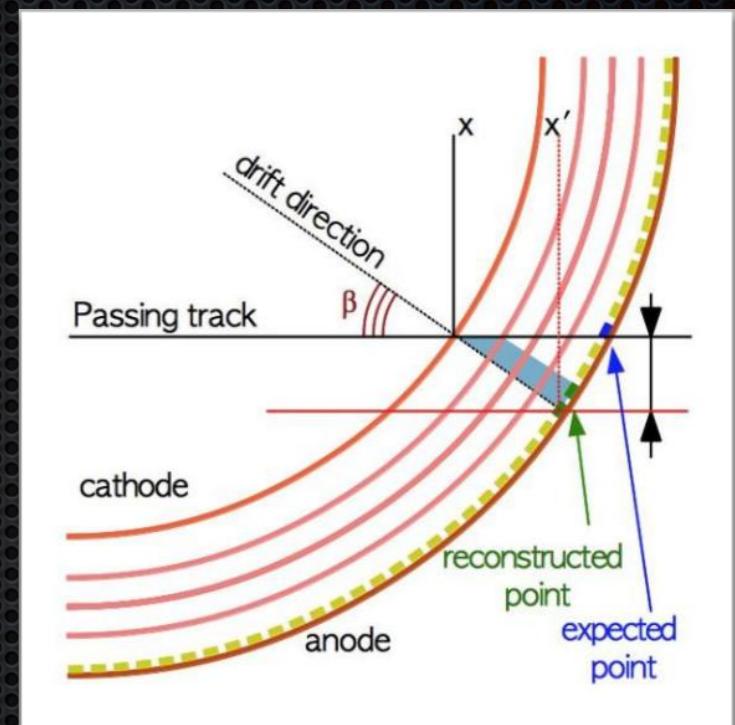
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 - + Shifts and rotations to align the IT
- ◎ Cosmic-ray muon data acquired with B-field ON
 - + Calibration of Non-radial track & B-field effects
 - + Corrections, Shifts and rotations from B-field OFF sample
 - + Study and apply B-field effects corrections

2. MAGNETIC FIELD

0.52 T B-field orthogonal to Triple-GEMs E-fields: **shift** $\Delta x(a_L)$ and **larger spread of the electron cloud**



Detector Calibration strategy

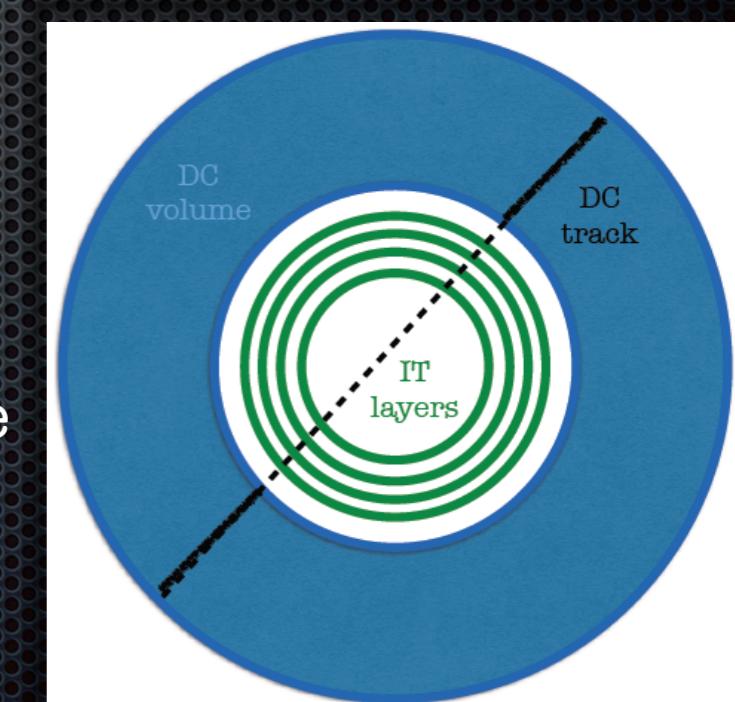
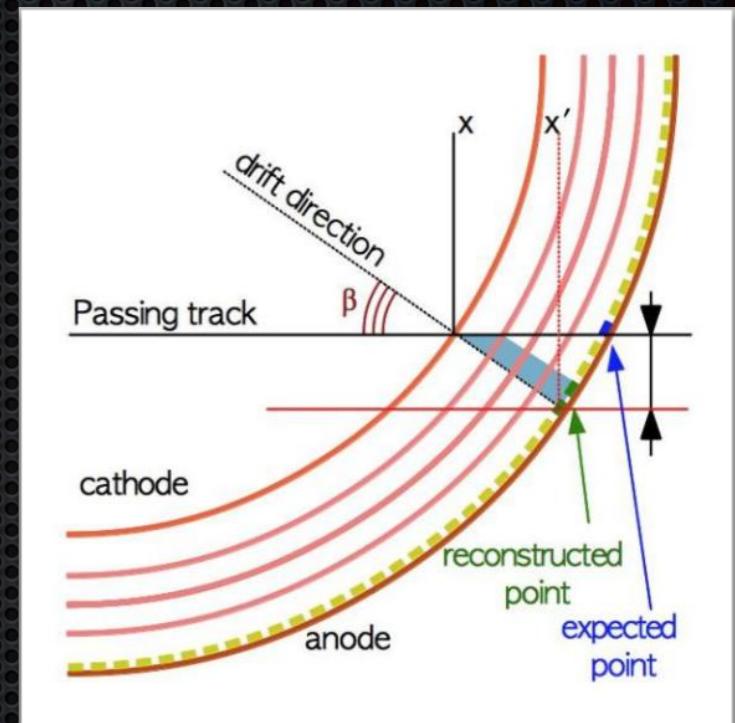
1. NON-RADIAL TRACKS

The angle formed by a track and the radial E-field direction introduces: **shift & spread** of the e- cloud

- ◎ Cosmic-ray muon data acquired with B-field OFF
 - + Calibration of Non-radial track effect
 - + Select DC tracks crossing IT at 2 points
 - + Corrections as a function of track parameters
 - + Shifts and rotations to align the IT
- ◎ Cosmic-ray muon data acquired with B-field ON
 - + Calibration of Non-radial track & B-field effects
 - + Corrections, Shifts and rotations from B-field OFF sample
 - + Study and apply B-field effects corrections
- ◎ Bhabha scattering events
 - + Check calibration of Non-radial track & B-field effects
 - + Corrections , Shifts and rotations from cosmic-ray muons with B-field ON sample

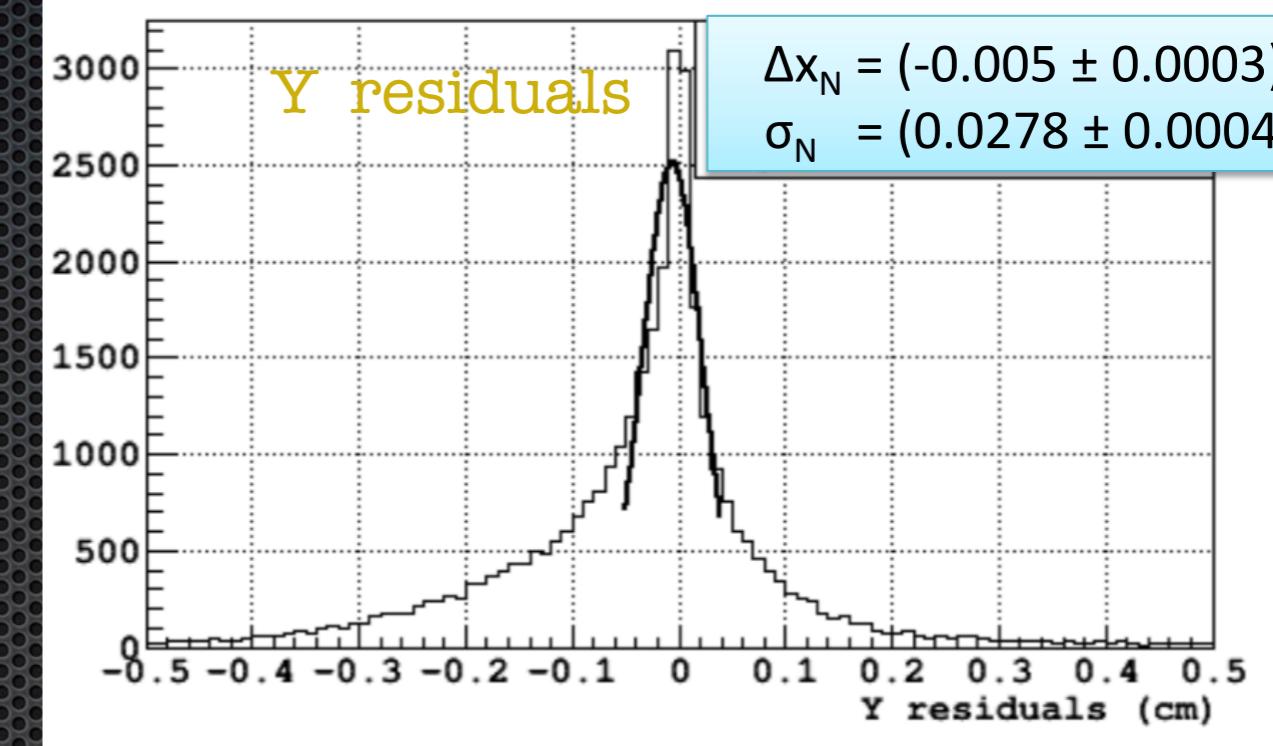
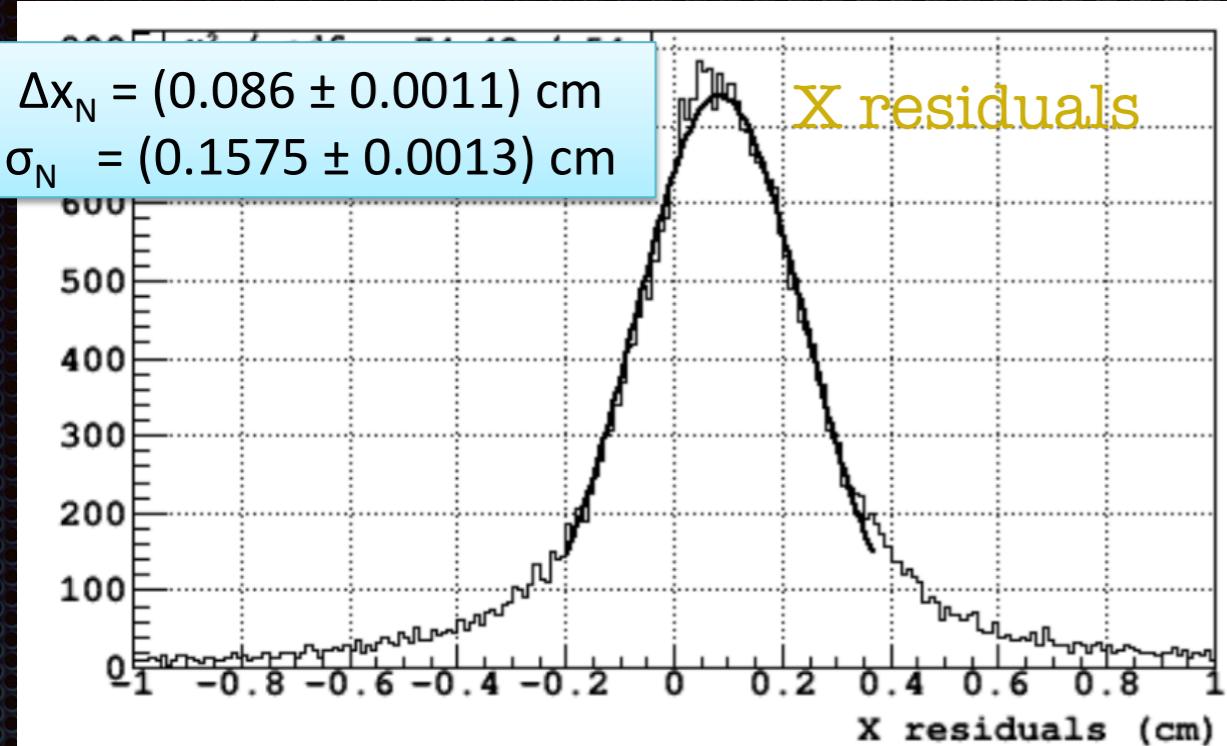
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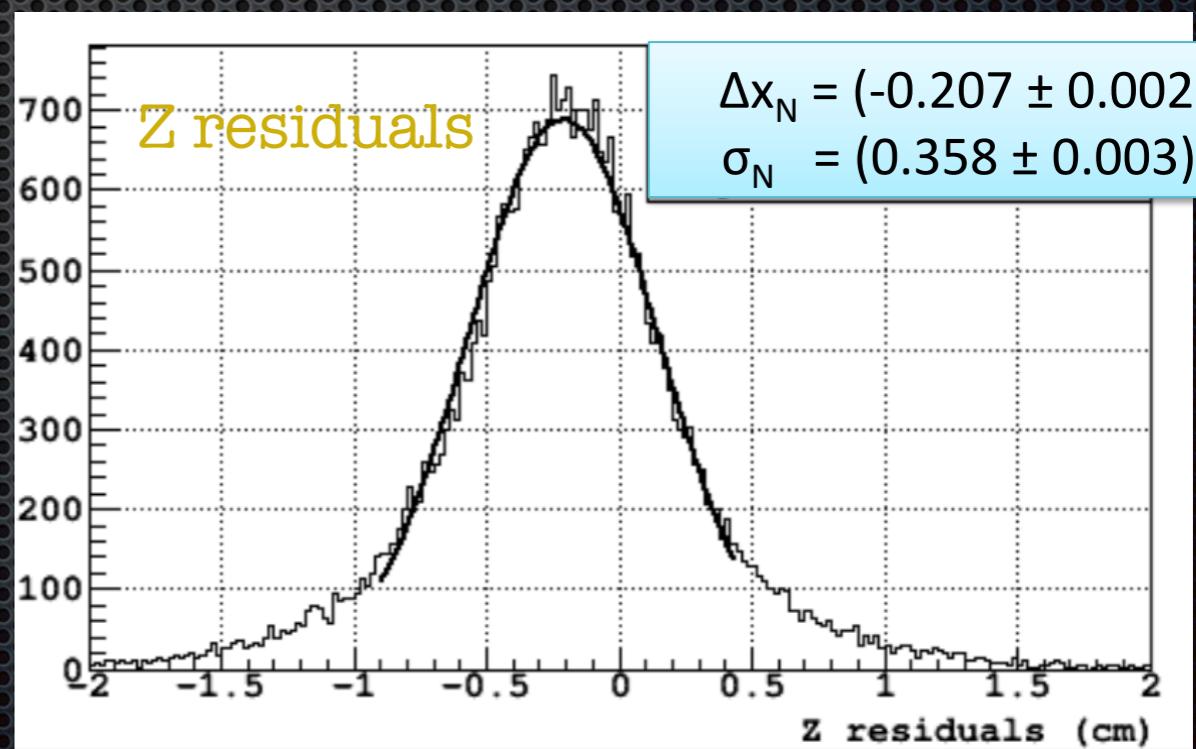
Starting point: Layer #4 residuals

Cosmic-ray muons with B OFF



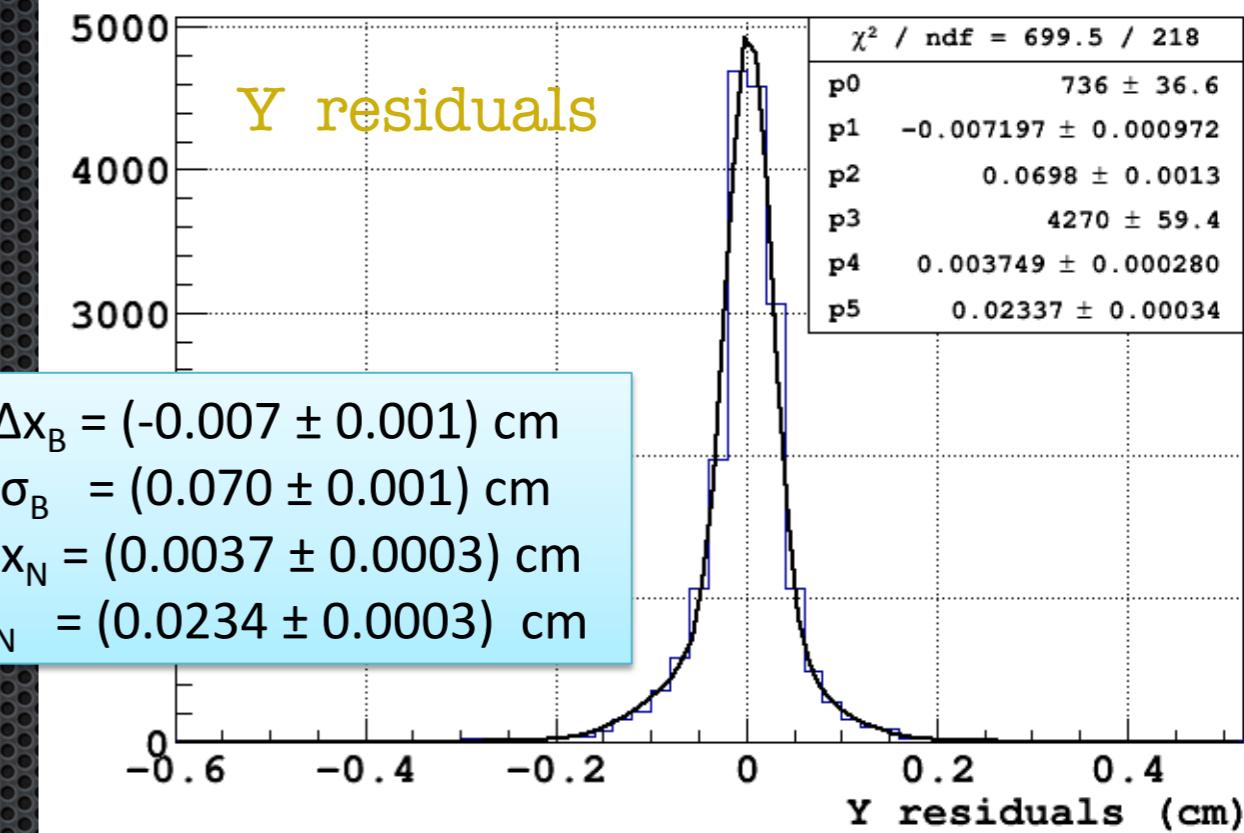
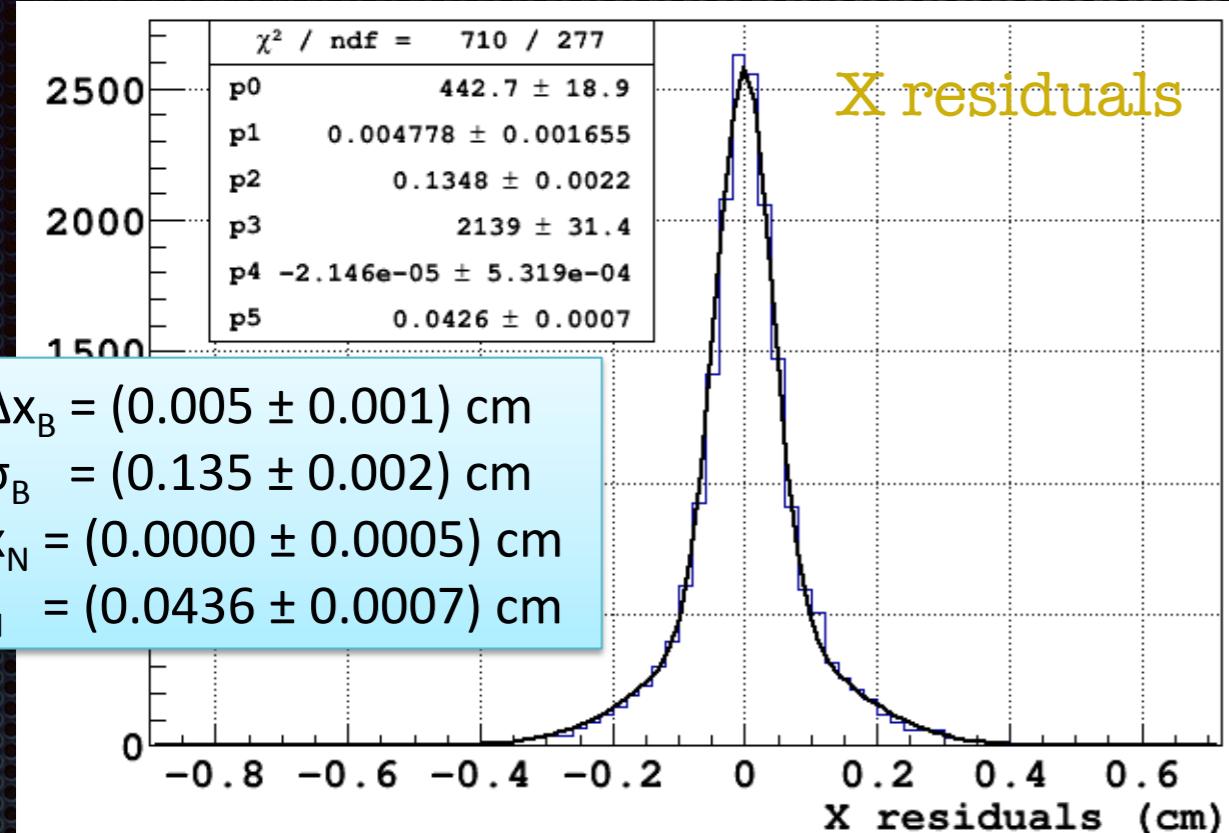
- ◎ Starting point before align & calib
- ⊕ Resx = 1.5 mm
- ⊕ Resy = 280 μm
- ⊕ Resz = 3.6 mm
- ⊕ Δx = 860 μm
- ⊕ Δy = - 50 μm
- ⊕ Δz = 2 mm

Convolution of DC + IT resolution



Detector Status: IT Calibration (I)

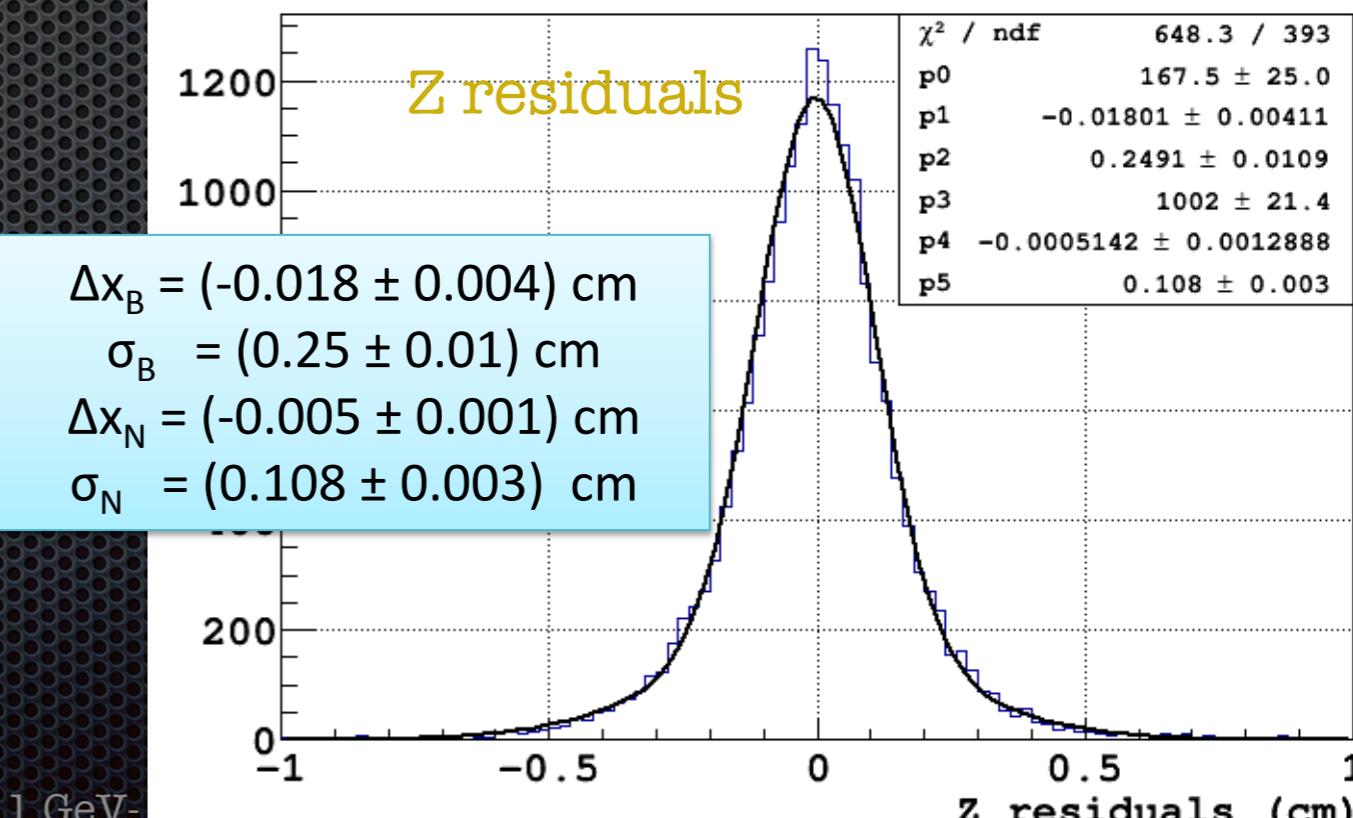
- ◎ Layer #4 residuals: 1st align & calib using cosmic-ray muons with B OFF



- ◎ Improvement with 1st align & calib

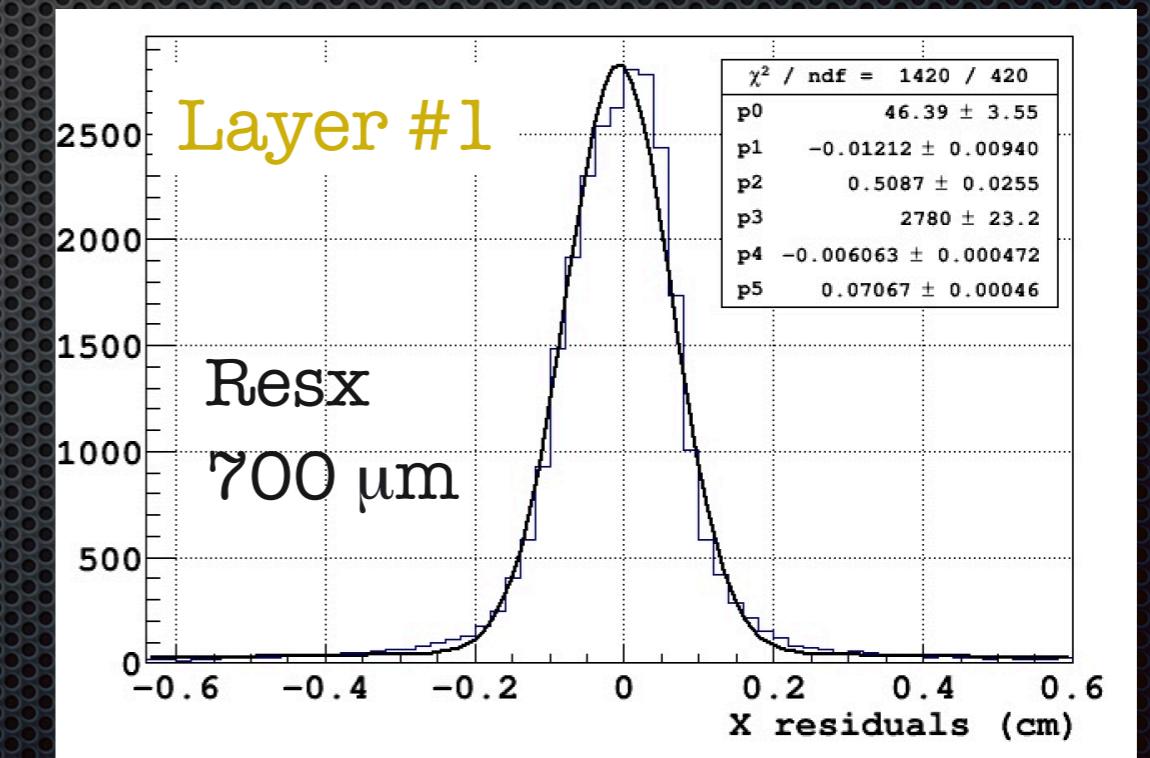
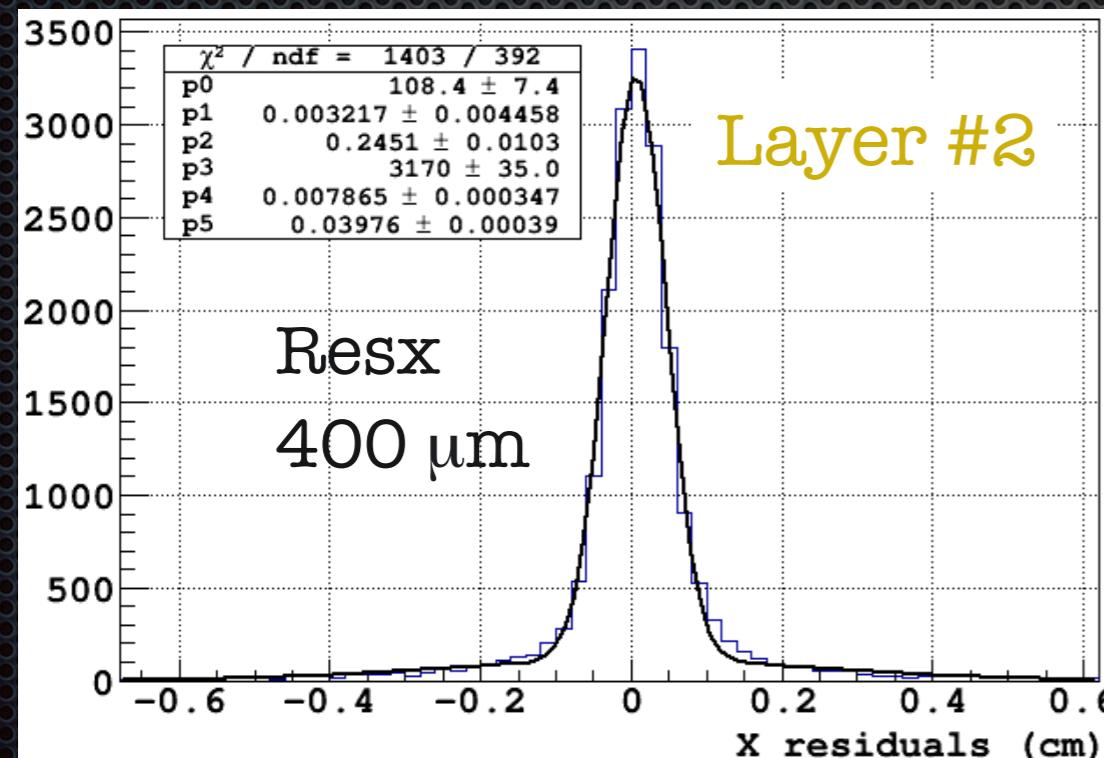
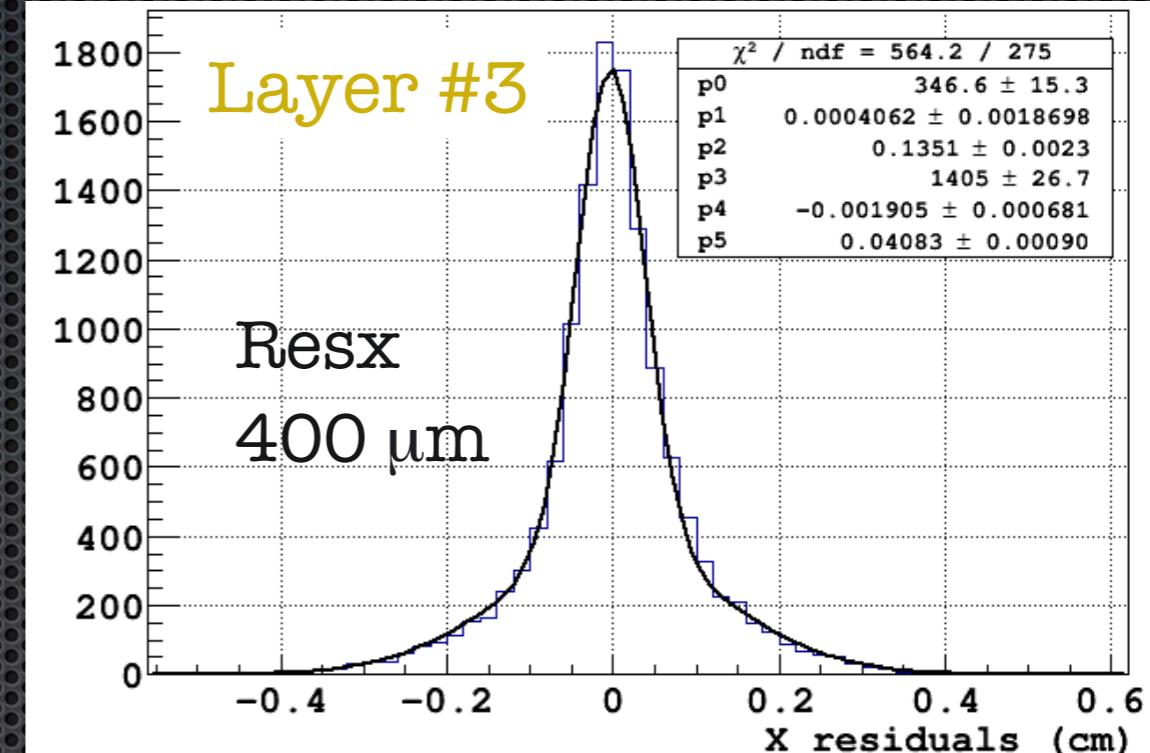
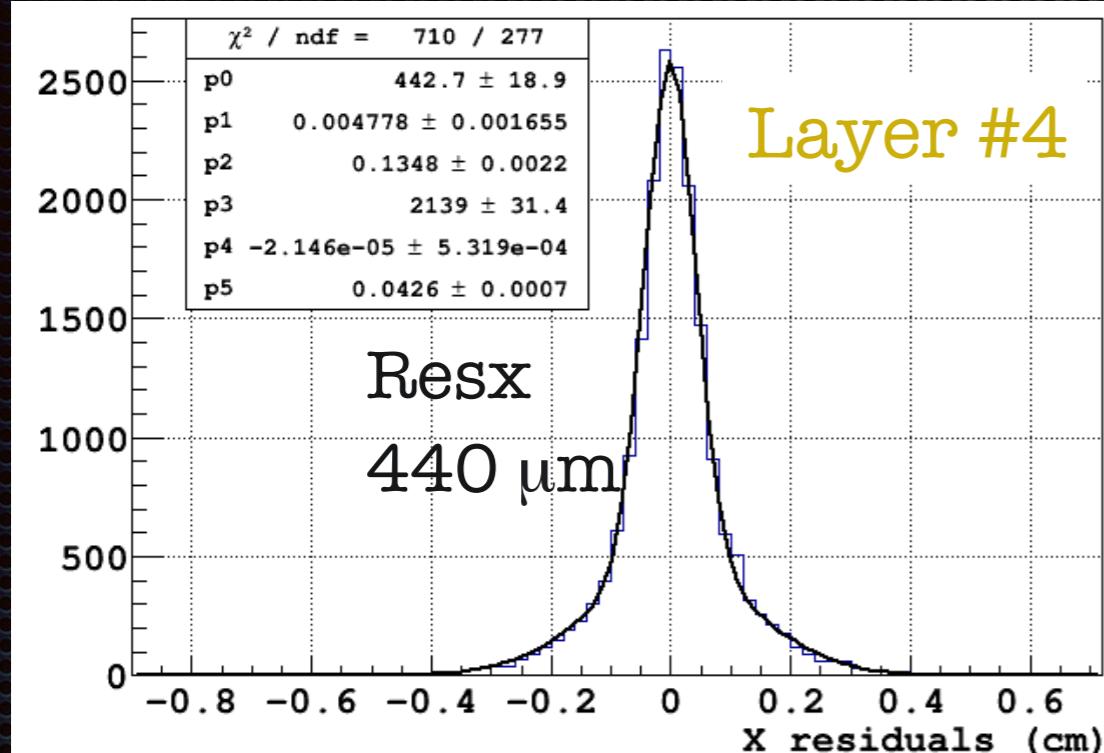
- Resx = 1.5 mm => 440 μm
- Resy = 280 μm => 240 μm
- Resz = 3.6 mm => 1.1 mm
- Δx = 860 μm => 50 μm
- Δy = - 50 μm => -50 μm
- Δz = 2 mm => 5 μm

Convolution of DC + IT resolution



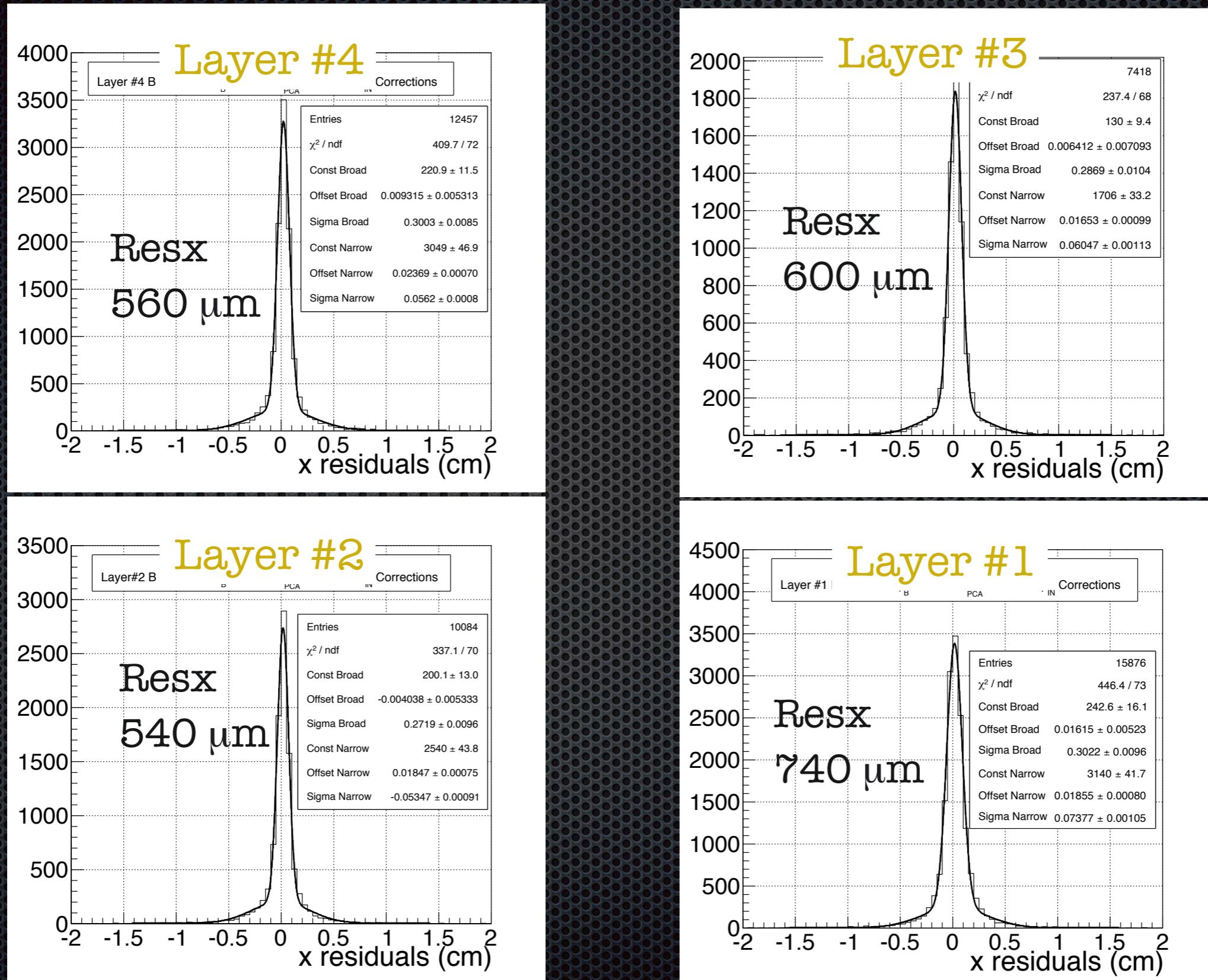
Detector Status: IT Calibration (II)

- ◎ 1st align & calib for all layers using cosmic-ray muons with B OFF



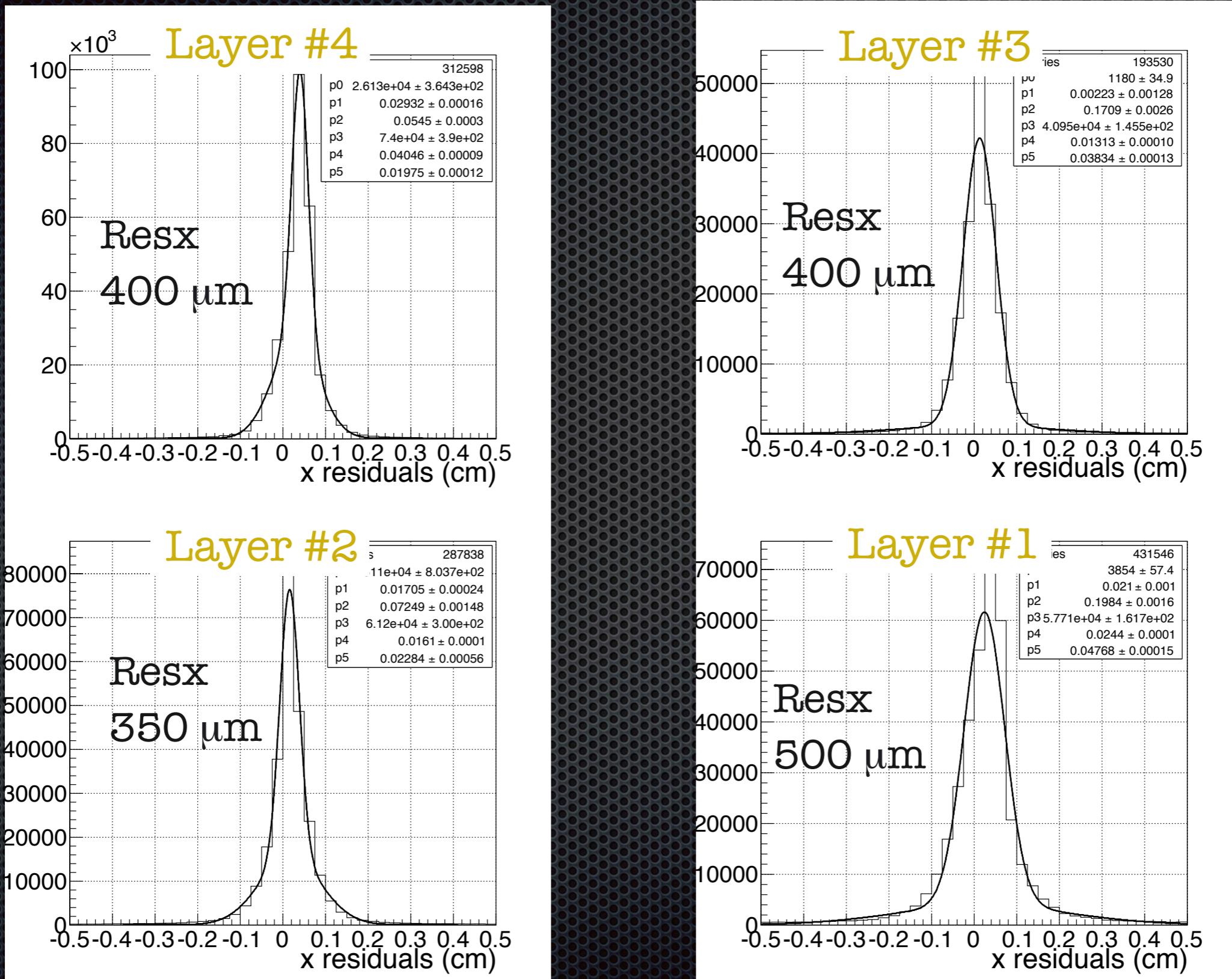
Detector Status: IT Calibration (III)

◎ 1st align & calib for all layers using cosmic-ray muons with B ON



Detector Status: IT Calibration (IV)

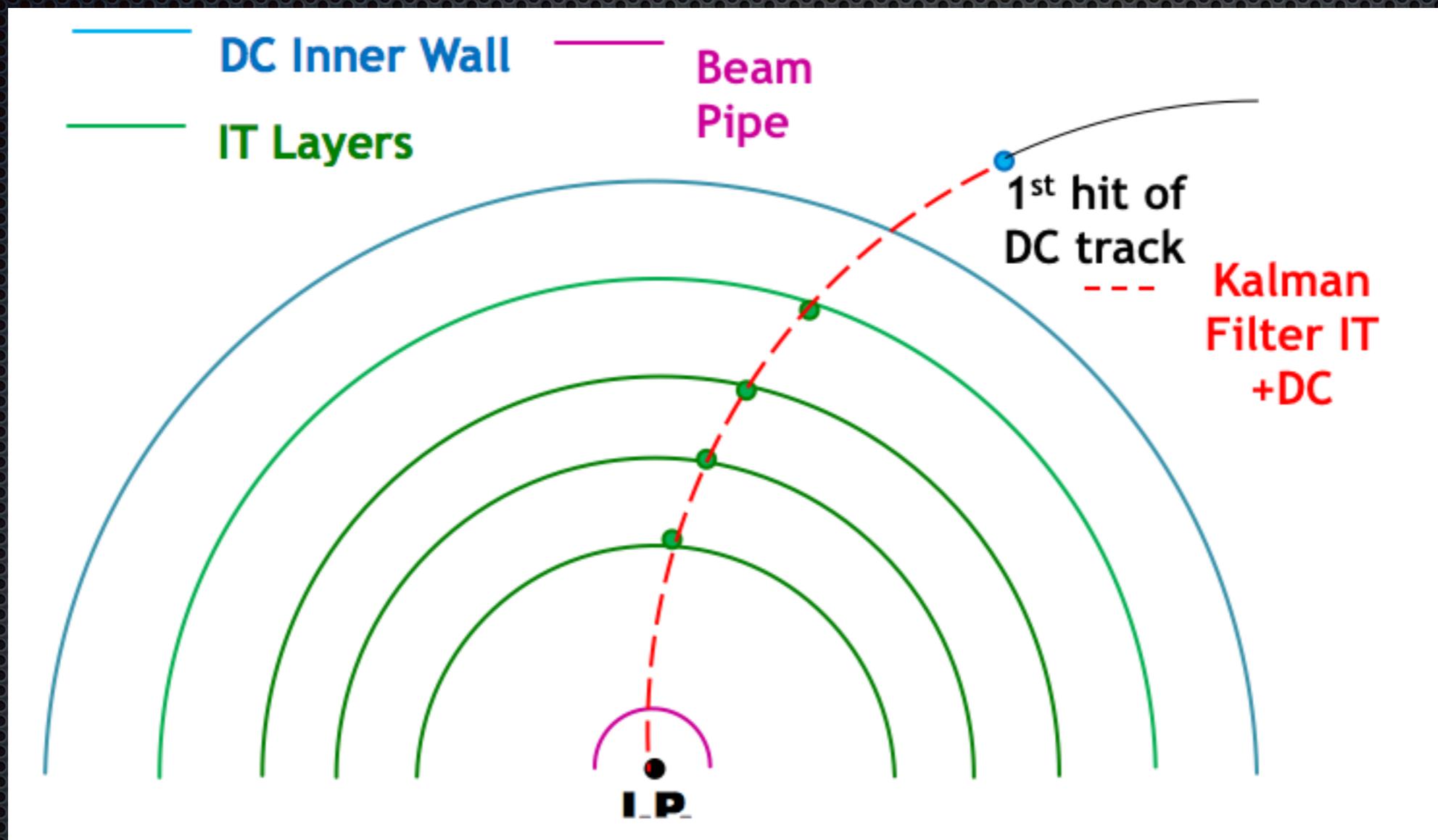
- Checking 1st align & calib with Bhabha scattering events



Tracking with IT+DC

Integrated tracking IT+DC (I)

- ◎ Starting with Drift Chamber reconstructed tracks
- ◎ IT Clusters reconstructed are added
- ◎ IT+DC Kalman filter
- ◎ Reconstruction procedure developed and tested with MC samples

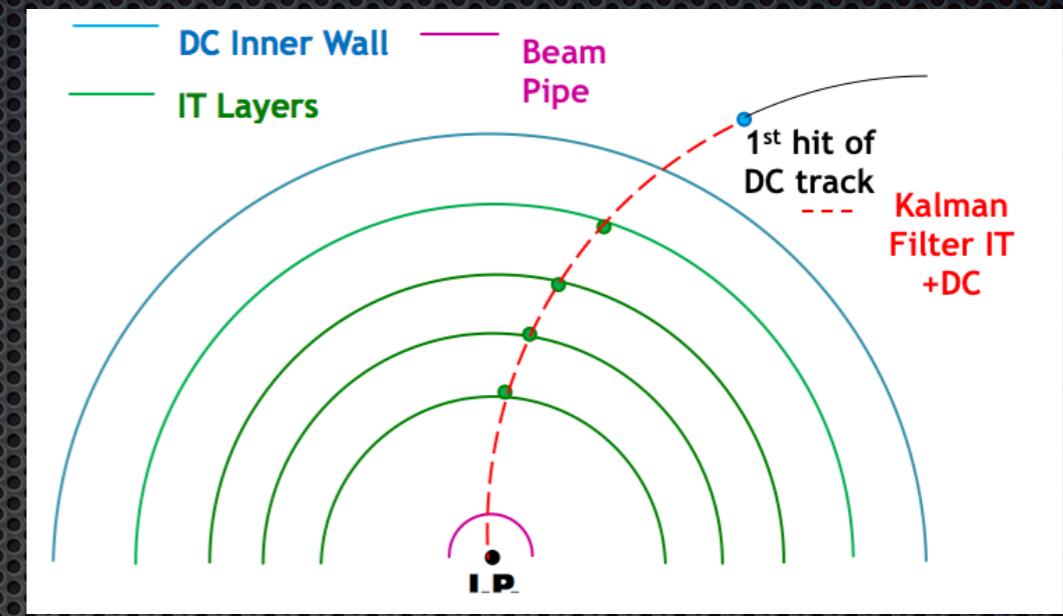


- ◎ Alignment and calibration parameters from cosmic-ray muon samples
- ◎ Validation with Bhabha scattering events

Integrated Tracking IT+DC (II)

- ◎ Bhabha scattering events selection using DC track reconstruction (as in the alignment & calibration) :

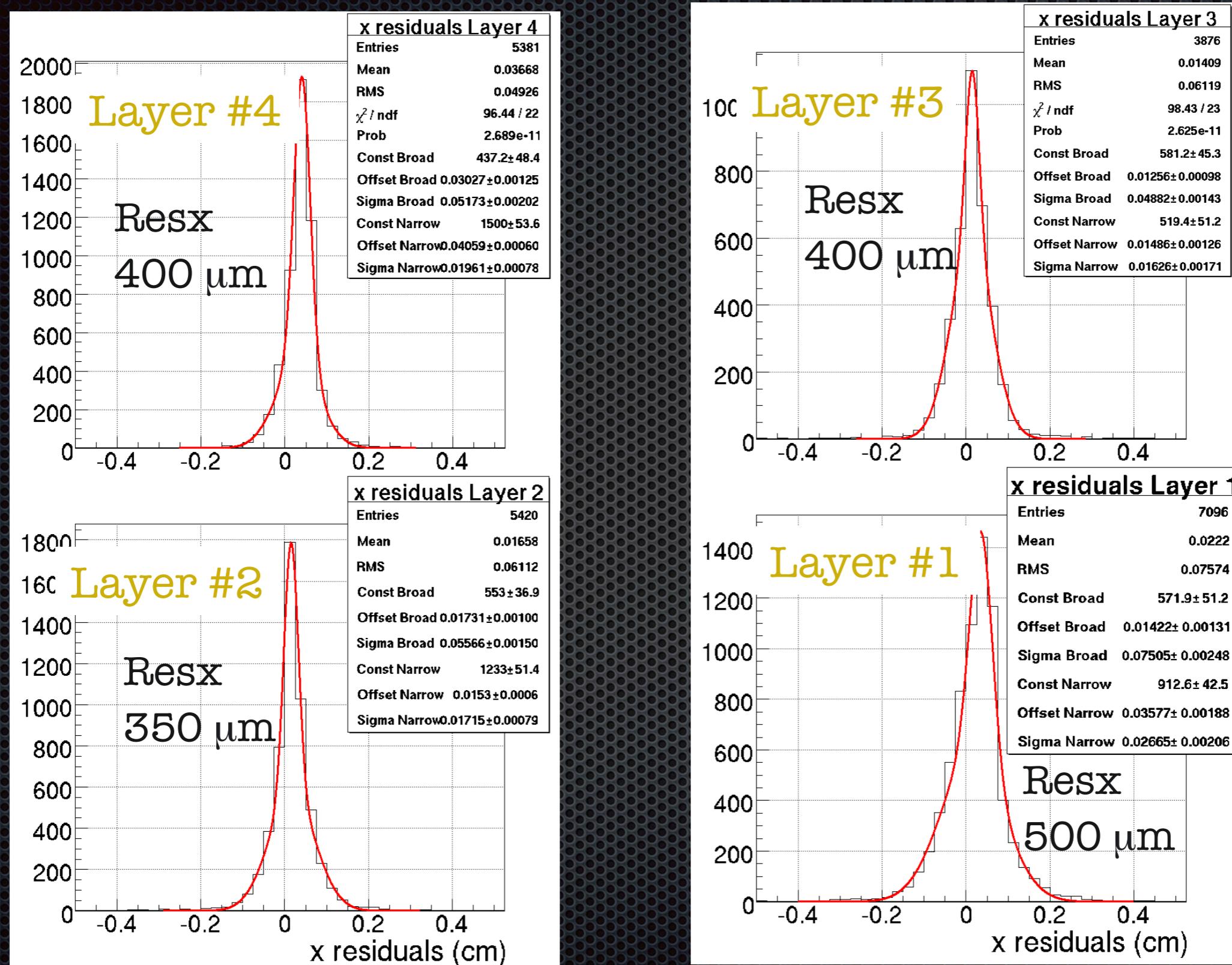
- ⊕ 2 tracks
- ⊕ $R_{PCA} < 5 \text{ cm}$ & $\text{abs}(z_{PCA}) < 5 \text{ cm}$
- ⊕ $p_T > 300 \text{ MeV}$
- ⊕ $R_{\text{FirstHit}} < 40 \text{ cm}$
- ⊕ $\text{NumFitHit} > 40$



- ◎ Insert Corrections , Shifts and rotations from cosmic-ray muons with B-field ON sample accounting for both Non-radial track & B-field effects
 - ⊕ For each DC track apply corrections parametrized as a function of the track parameters
 - ⊕ For each DC track apply corrections average B-field correction
- ◎ Validate the procedure Obtain residual distribution with the same procedure used in the standalone code for alignment and calibration: residual between DC extrapolated track and closest IT cluster
- ◎ Use calibrated IT cluster for IT+DC integrated tracking

Insert 1st calibration & validate

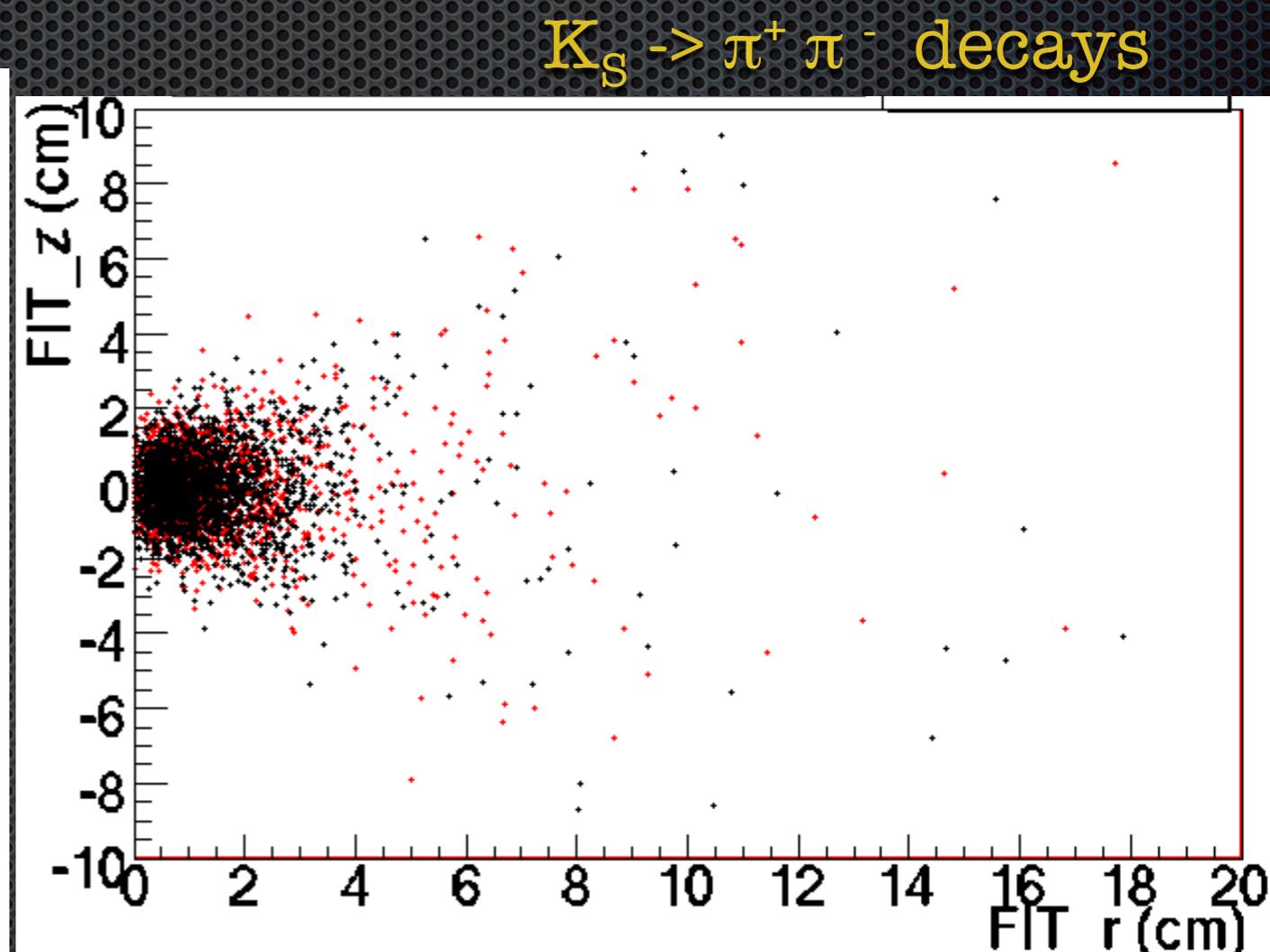
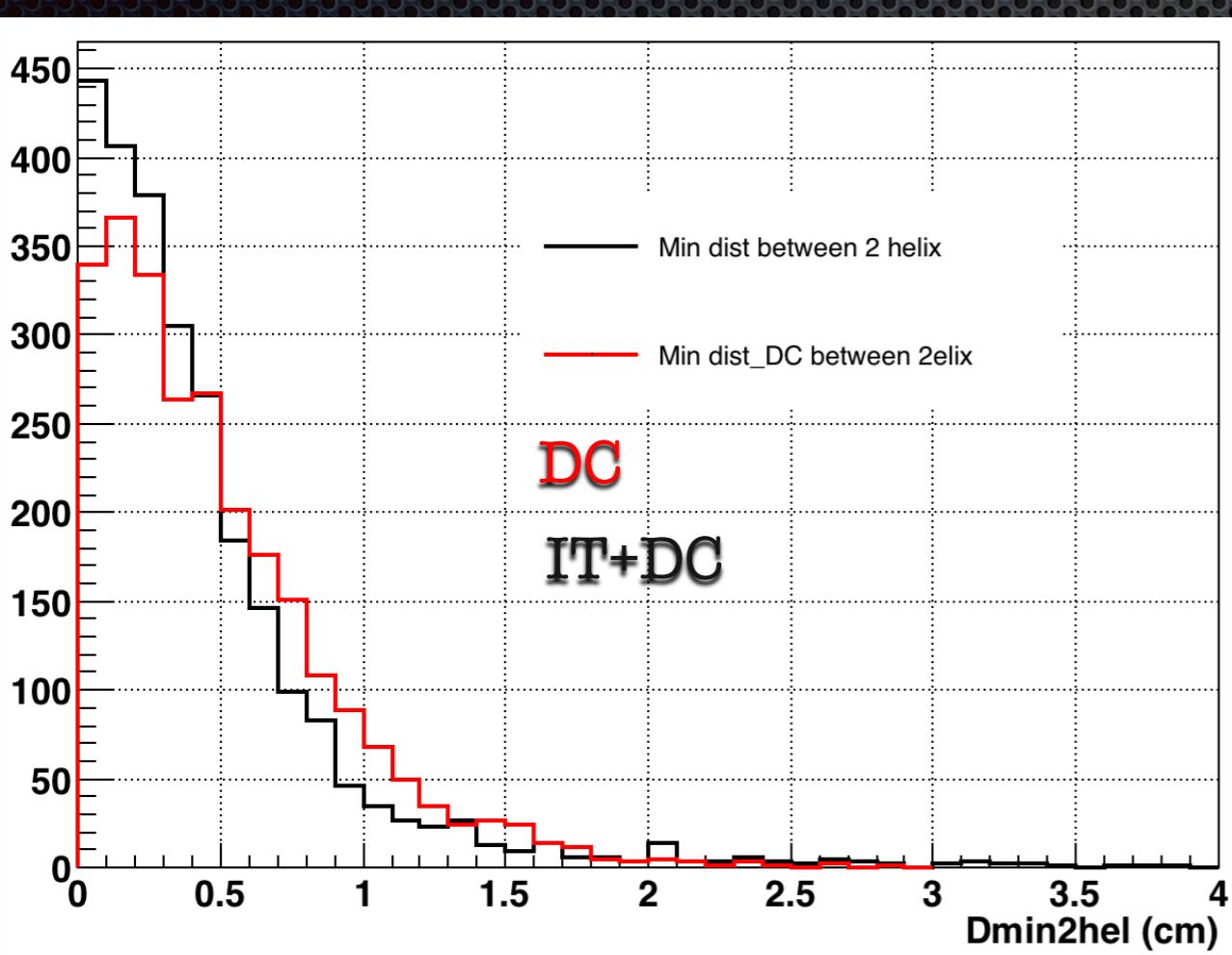
- ◎ Residuals between DC extrapolated track and closest IT cluster as in align & calib



Bhabha scattering events

Integrated tracking: Kaon decays

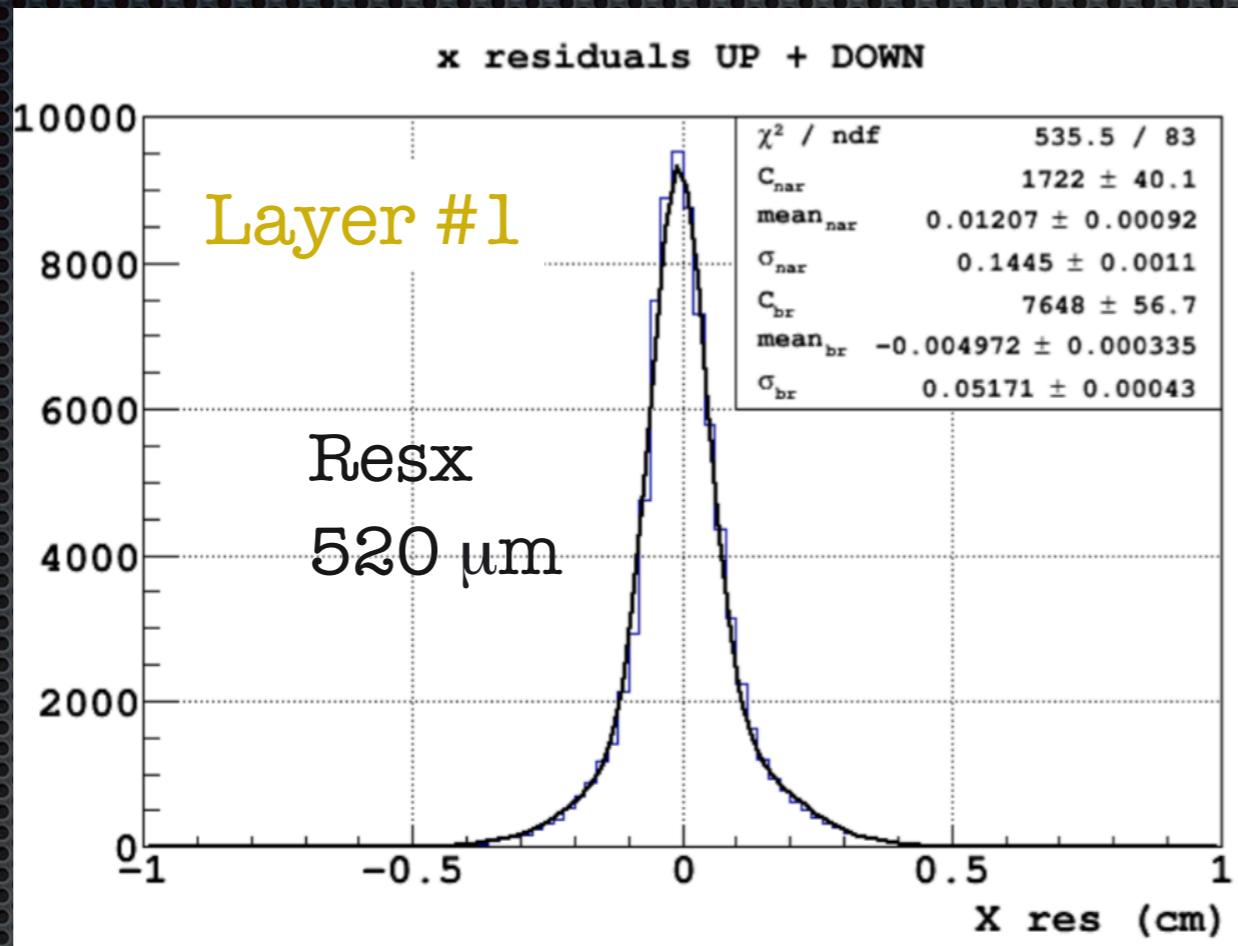
- ◎ Neutral Kaon data stream and selection of $K_S \rightarrow \pi^+\pi^-$ decays
- ◎ Use 1st align & calibration parameters
- ◎ Simple vertex finder based on minimum distance between extrapolated tracks
- ◎ Comparison between IT+DC and DC simple vertex position



Min distance between helixes

IT reconstruction activities

- © Room for calibration improvement from optimization of correction functions
Layer #1 Resx $\approx 700 \mu\text{m}$ from 1st alignment & calibration with B Off



Refine B-field On calibration & Insert refined calibration in Kalman (for all layers)

- © IT+DC integrated tracking performance optimization
Using Bhabha scattering events
- © 1st version of data reconstruction with IT+DC tracking & official vertexing ready
Validation and performance study ongoing using both Bhabha scattering events and Neutral Kaon decays

Conclusions

- ◎ KLOE-2 Inner Tracker is the First CGEM detector used in high-energy physics experiment
- ◎ 1st Detector Alignment and calibration performed
Challenging. Never done before.
Calibration obtained for all layers using both cosmic-ray muon data with and without B-field and checked using Bhabha scattering events.
Room for improvement as shown for Layer #1
- ◎ IT+DC tracking with Kalman filter
Integrated tracking using 1st align & calibration parameters
Optimization ongoing using Bhabha scattering events
- ◎ 1st version of reconstruction with IT+DC tracking & official vertexing ready